Report on the Technical Evaluation of Underground Laboratory Sites[1]

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Summary

The Technical Assessment Sub-Committee has investigated four proposed national underground science laboratory sites in the United States and visited existing laboratories in Italy and Japan. In addition, the Sub-Committee has met twice with the full Committee and interacted extensively through site visits, telephone and email with advocates for the various sites. The Sub-Committee has also solicited independent engineering and geological advice and has identified and visited on its own several potential horizontal access sites in the California-Nevada border region. In aggregate, the Sub-Committee has committed more than one person-year to its studies.

The site visits and discussions led the Sub-Committee to identify 28 individual factors, grouped into 11 categories that are relevant to site selection. The relative importance of these factors varies. The Sub-Committee reports information about all of these factors both for the proposed sites and for the laboratories in Italy and Japan. The Sub-Committee believes that in many respects the Italian National Laboratory of Gran Sasso (LNGS) sets a "baseline" that a new American laboratory must exceed. This criterion has led the Sub-Committee to an assessment that is summarized here and discussed in the report.

All four sites investigated in detail are acceptable for underground research. The depth factor alone justifies narrowing the site search to Homestake and San Jacinto sites for a primary national facility. These two sites may well be equivalent within the uncertainties of our criteria and assessments, but the availability of the Homestake site is more time-dependent. Selecting between these sites likely requires consideration of other factors, such as the success probability of various development scenarios and tolerance for risk. With respect to Carlsbad Underground National Laboratory and Soudan Laboratory, the Sub-Committee believes that underground science that exploits the special advantages of each of these sites should and will likely continue. The Sub-Committee also suggests continued study at an appropriate level of the California-Nevada border sites, to facilitate a deep alternative if both the Homestake and San Jacinto sites prove infeasible.

The Sub-Committee believes the case for a multi-purpose underground science laboratory is compelling. The technical considerations assessed by the Sub-Committee indicate that the project is feasible. Within one to five years, the United States can have a world-leading facility to advance a wide

range of important science that requires very sensitive detectors and a very low background environment. The Sub-Committee believes this initiative should proceed on the fastest possible time scale.

This report is organized in the following manner. The first section introduces the charge, structure, methodology and approach of the Technical Sub-Committee. Section 2 discusses summary characteristics and attributes of each of the principal sites or laboratories visited by the Sub-Committee. Section 3 explains the evaluation criteria used in assessing the sites and the comparative characteristics of the sites and laboratories to these characteristics. The Sub-Committee analysis and summary are presented in Section 4. Appendix A is a glossary of mining and excavation terms whose understanding aids in the discussion of the technical aspects of the various sites. Appendix B is the criteria document that was communicated to the various site advocates in order to ensure that all sites would be studied and evaluated in the same manner. Appendix C is a summary table of specific items and cost information presented by the four major candidate sites. Appendix D presents the findings and preliminary evaluation of possible alternative candidate sites in the California-Nevada border area.

1. Introduction

The Technical Evaluation Sub-Committee was charged with developing a set of criteria to evaluate sites for a possible national underground physics laboratory in the United States, evaluating a set of sites against those criteria and making an initial assessment regarding site selection. The Sub-Committee gratefully acknowledges financial support for its efforts from the National Science Foundation through the Institute for Nuclear Theory at the University of Washington and from the U.S. Department of Energy through the School of Physics and Astronomy at the University of Minnesota. The Sub-Committee also wishes to express its thanks for the gracious hospitality it has received from site proponents and interested citizens during its site visits, and the cordial reception accorded to Committee members during site visits to existing underground physics laboratories outside the United States.

A brief summary of the Sub-Committee's work is as follows: The Sub-Committee retained the firm of CNA Engineers of Minneapolis to provide expertise and advice to the Committee during its study. CNA Engineers has 17 years of experience in engineering design and construction supervision at Soudan Underground Physics Laboratory and has worked on numerous underground transportation, workspace and sanitation projects in different parts of the world. Sub-Committee members participated in a meeting with the full committee in Alexandria, Virginia, on December 14. On January 9-11, Sub-Committee members visited the Homestake Mine in Lead SD, followed by a visit to the Soudan Mine, MN on January 12. Sub-Committee members next visited the National Laboratory of Gran Sasso in Abruzzo, Italy, on January 29-30. They next visited the Kamioka Laboratory in Mozumi, Japan on February 12-13, followed by a visit to the WIPP site near Carlsbad NM on February 16. Several members of the Sub-Committee visited possible site for a horizontal access laboratory along the California-Nevada border on February 21-23. Sub-Committee members toured the San Jacinto site near Palm Springs CA on February 28 and March 1. The Sub-Committee then met in Berkeley CA on March 2 and reported to the full Committee on March 3-4. During this entire process, the members of the Sub-Committee exchanged numerous emails and telephone calls with each other, members of the full Committee, site proponents and other interested persons.

To assist site proponents in the preparation of pre-proposals and to help guide its own thinking, the Sub-Committee prepared a document entitled *Criteria for Technical Evaluation of an Underground Laboratory Site*, which is included as Appendix B. The "Criteria" document includes work breakdown structure (WBS) for both the capital and operations activities of a national underground laboratory. For specificity, the "Criteria" document describes four example detectors. Detector A is a modest-sized, ultra-low-background detector of the type that might be used for a bb decay or a cold dark matter experiment. The salient feature of Detector B is a large inventory (perhaps 1 kiloton) of flammable liquid scintillator, similar to a super-Borexino or a super-KamLAND. Detector C has an even larger inventory of a liquid cryogen, for example, 5 kilotons of argon. Finally, Detector D is an ultra-K detector, containing perhaps 0.5 megatons of water. While these four example detectors do not include all possibilities, they are good indicators of the types of stress that will be placed on a national underground laboratory. Thus, they provide a good metric for site evaluation.

The Sub-Committee believes that in many ways the National Laboratory of Gran Sasso (LNGS) provides a *baseline* for evaluating national underground laboratory proposals and sites in the United States. While the LNGS seems to be currently full and has a planned program of experimentation well into the future, the Sub-Committee believes that LNGS could and quite likely would make space for a new compelling and well-planned experiment. Thus, the Sub-Committee believes that merely duplicating the capabilities of LNGS in the United States is not sufficient. The new United States National Underground Scientific Laboratory (USNUSL) should enable a new generation of detectors with significant increases in sensitivity over what is currently available. This goal of significant increase in sensitivity underlies the discussion in this report.

The Sub-Committee believes that historically physics detectors have attained increased sensitivity in two ways—increasing signal and decreasing background. One or more of the following specific strategies are likely necessary to achieve the goal of higher sensitivity:

1. Increase target or detector mass
2. Use more sensitive and likely more exotic materials, for example, increasingly use materials which are more costly, unstable, toxic, flammable, explosive or cryogenic
3. Reduce both direct and induced cosmogenic background with increased depth underground
4. Reduce radioactivity background by locating in less radioactive rock, by improved local shielding and/or by better control of radon
5. Increase signal and/or reduce background by achieving lower levels of naturally occurring radioactive impurities
6. Increase signal and/or reduce background by using more and/or better electronics, software algorithms and computer processing

The first five of these strategies directly relate to the properties of the proposed USNUSL and its infrastructure. Strategies involving electronics and computer processing or software can presumably be implemented at any laboratory site. The Sub-Committee criteria for evaluating possible laboratory sites are thus related to the first five of these strategies to achieve a new level of sensitivity in a wide range of low background detectors.

The Sub-Committee's methodology during its visits was to engage the site proponent's in vigorous discussion about how to prepare the best possible case for each site. First, the Sub-Committee received information from the advocates, in some cases in advance and in others during the site visit. The Sub-Committee then inspected the physical site. Next the Sub-Committee discussed the information received, the on-site observations and the information received from its consultants with the site advocates. In some cases, these discussions were quite extensive and resulted in major re-thinking of their ideas by the site advocates. The Sub-Committee then received additional and, in some cases, new information from the site advocates. Finally, the Sub-Committee turned to an evaluative mode and attempted to assess all the information it had received from the site advocates, from its own observation and from its consultants with regard to each site.

We note a caveat that should be used in considering our report. Our entire process was very short. We very much appreciate the responses we received from site advocates under extreme time pressure, but we realize, that of necessity, the scope of these responses was limited. We restricted advocates to 10-page pre-proposals, again because of the time constraints. Our process is perhaps best regarded as a preliminary technical review. While we are confident of the thrusts of our analyses, we believe the scientific communities should subject actual proposals for a national underground science laboratory to extensive peer review.

2. Sites

The Sub-Committee has investigated two existing foreign laboratories—National Laboratory of Gran Sasso (LNGS) and Kamioka, four proposed sites—the Homestake Mine, San Jacinto, the Soudan Underground Physics Laboratory and the Waste Isolation Pilot Plant (WIPP). Near the end of the Sub-Committee's consideration process, the proponents of a laboratory at WIPP renamed their proposal Carlsbad Underground National Laboratory (CUNL) and that name will be used to describe the WIPP site in the remainder of this report.

The Sub-Committee also sought to locate possible sites without current proponents, so-called *green-field* sites. A laboratory built at an arbitrary location would require two new vertical shafts or a single new vertical shaft divided into two independent shafts by a fire-rated barrier. The construction cost of either arrangement to a depth of 2,500 m is likely greater than $200 million not including the cost of laboratories, surface facilities or detectors. The Sub-Committee believes that it would be difficult to justify such an expense. A more feasible alternative is to find other sites similar to Mt. San Jacinto, where the ground elevation changes so rapidly that a depth of 2,500 m could be achieved with a horizontal access adit or tunnel of length 5,000 m to 10,000 m. The construction cost for access in these sites is perhaps 50% of the cost of sinking two shafts. In addition, the resultant horizontal access has lower operating costs, lower costs for excavation of laboratories and lower costs for detector installation than a vertical shaft laboratory. The Sub-Committee identified many sites, but selected four such sites in the vicinity of the California-Nevada border for on-site investigations. These sites are presented here as a composite in a very preliminary context as the California-Nevada sites.

2.1 National Laboratory of Gran Sasso (LNGS): The LNGS is located just outside Assergi between

L'Aquila and Teramo in the Abruzzo region of Italy, approximately 150 km east of Rome. The LNGS was built as a supplement to a 11 km double tunnel on the A24 *autostrada* that traverses the Italian peninsula west-to-east from Rome to the Adriatic coast. The underground laboratory with a depth of 3,800 mwe consists of three primary halls of approximate dimension 20 m by 100 m by 20 m high. The access to the LNGS is by vehicle from the westbound *autostrada* tunnel. The experimental halls are connected by a series of underground drifts, some of which are large enough to permit access by a standard highway semi-trailer to each of the experimental halls. The LNGS has a campus consisting of several buildings housing offices, laboratories, supply rooms, machine shops, dormitory rooms and a cafeteria about 1 km outside the western tunnel portal. Access from this campus to the underground laboratory requires driving onto the *autostrada*, through the entire length of the eastbound tunnel, accessing a special ramp and then driving approximately halfway through the westbound tunnel. The return to the outside campus is shorter, requiring only a drive halfway through the westbound tunnel and then the 1 km to the campus.

The LNGS has about 15 years of excellent operating experience. The replacement of detectors by new detectors is now an ongoing process. An expansion of the LNGS was authorized in 1990, but has been delayed by environmental and other concerns. The LNGS is well subscribed by both old and new detectors, but could likely accommodate a totally new detector within the next five years, if the detector were funded and had a compelling physics rationale. LNGS is a truly international laboratory.

2.2 Kamioka Observatory Laboratory (Super-K and KamLAND): The Kamioka Laboratory is located near Mozumi, about 75 km south of Toyama, a port on the Sea of Japan. Mozumi is approximately 300 km west of Tokyo. The Kamioka laboratory was built in a mine complex at a shielding depth of 2700 mwe. It was initially accessed via a 7 km mine rail adit beginning on the mountainside above Mozumi. The primary access now is through a 3 km vehicular adit capable of passing a standard highway semi-trailer. The adit portal is located about 10 km by road from Mozumi. The underground facilities consist primarily of two main laboratories both upright cylinders with domed roofs. The smaller laboratory with a liquid volume of approximately 10,000 m^3 once housed the Kamioka detector. The KamLAND liquid scintillator detector is now being installed in this hall. The second hall, with a liquid volume of approximately 50,000 m^3 houses the Super-Kamiokande detector. The complex includes a few drifts that are used for access and some stub drifts that are used for control rooms, storage and vehicle parking.

The Kamioka Laboratory has an office building and a dormitory/cafeteria building, both located in Mozumi. The round-trip from Mozumi to the laboratory requires about 30 minutes. Because Mozumi is very small, population less than 1,000, many visiting physicists live about 3/4-hour drive from Mozumi, towards the coast, where the population is larger and services more numerous.

2.3 Carlsbad Underground National Laboratory: The proposed CUNL would have an underground laboratory located at the Waste Isolation Pilot Plant, a government-owned, DOE facility. WIPP is located about 50 km east of Carlsbad, Eddy County, NM in the Permian Basin, a large deposit of halite and anhydride layers with underlying rich deposits of petroleum and natural gas. The office-laboratory-stock room complex for CUNL would likely be located in Carlsbad, possibly on land owned by the State of New Mexico and used by New Mexico State University for an environmental monitoring center.

The CUNL laboratory site is an extraordinary complex of surface and underground facilities, including state-of-the-art hoisting, ventilation and materials handling systems. The underground site is completely dry; no pumping is required. The current underground complex is located in an extensive salt formation at a depth of 1,600-1,800 mwe. The CUNL proponents have developed a plan to locate a laboratory complex near the bottom of the halite, a depth of 3,000-3,200 mwe. The site advocates and their technical consultants report that depths below 3,200 mwe cannot be achieved at CUNL because of the risk associated with digging into the hydrocarbon deposits known to exist below the halite and anhydride beds.

2.4 Homestake Underground National Laboratory: The Homestake Gold Mine is located in Lead, Lawrence County, SD. This mine has been worked for approximately 125 years and has more than 800 km of drifts at various levels with the deepest workings at 2,600 m. The mine has two active shafts (Yates shaft and Ross shaft) with multi-compartment hoists that reach a level 1,600 m below the ground. From there, access to the lower levels is via an internal winze (shaft) or via a ramp system that accommodates rubber-tired vehicles. The Homestake mine has a large number of surface buildings, many of which are quite old and probably not of high utility for an underground laboratory. The heads of both shafts are located within a 5-minute drive of the center of Lead. The nearest commercial airport at Rapid City is about an hour drive to the east.

The Homestake mine has a number of existing underground rooms that are for used for various support functions at a variety of depths down to 2,100 m. These rooms are typically 20 m by 50 m by 10 m in height. The rooms are generally stabilized with conventional techniques such as rockbolting or shotcreting, but appear stable over time intervals of more than 10 years. Homestake could house laboratories at several different depths with a maximum possible depth of about 7,200 mwe. Because of temperature and lithostatic pressure considerations, the bulk of the low background laboratories would likely be located at 6,500 mwe. Because of the configuration of the mine systems, a likely location of less deep laboratories would be at about 4,500 mwe. Converting the mine to a national underground laboratory would require renovation of the mine's mechanical and access systems, closing off a large part of the mine that will not be used, and construction of new caverns to house detectors. These detector laboratories would be located in non-ore-bearing rock. The Homestake Mining Company also requires an indemnification against liabilities as a result of science activities. This important issue appears to require federal legislation.

2.5 Mount San Jacinto: Mt. San Jacinto is located in Riverside County CA with its base rising at the western edge of the City of Palm Springs CA. An aerial tramway operated by a public authority traverses up most of the mountain's western slope. The portal for a proposed horizontal access adit (tunnel) to the Mt. San Jacinto underground laboratory would begin about 1 km to the west of the Tramway Valley Station, about 100 m south and connected to the Tramway access road. The area around the portal is currently an overflow parking lot for the Tramway, that has also been used to store refuse from the recent Tramway renovation. The land required for the laboratory is mostly state-owned, either by the Tramway authority or as part of a state park. The site of an external campus for the San

Jacinto laboratory is not yet defined, although the advocates suggest a wide availability of sites in Palm Springs, a roughly 30 minute round trip from the underground laboratory. These sites include private land and public land assigned to higher education.

The initial cost of the proposed San Jacinto Laboratory is significantly affected by the length of the access adit, which in turn depends on the required laboratory depth. The Sub-Committee believes the most desirable option achieves a depth of 6,500 mwe with a slightly upward-sloping adit of approximately 7,700 m in length. Approximately 10% more depth could be achieved with a somewhat shorter, downward-sloping adit, albeit with an additional operating cost because of the need to pump water.

2.6 Soudan Underground Laboratory: The Soudan Underground Laboratory is located at a depth of 2,200 mwe in St. Louis County in northeastern Minnesota. The Soudan Laboratory is located in a hematite mine converted to a state park in the 1960's. Physics experiments at Soudan started in 1981. Since that time, two large experimental halls have been excavated, each approximately 15 m wide by 12 m high. The Soudan 2 hall is about 70 m in length; the MINOS hall is approximately 100 m in length. Currently, the Soudan Laboratory has only a single usable shaft with a cage dimension of approximately 1 m wide by 2 m deep with the possibility of carrying lengths up to 12 m and weights up to 6 tons. The Soudan Laboratory is the target for a Fermilab neutrino beam that is currently under construction.

Because of its shallow depth, the advocates of the Soudan Laboratory believe that it is best suited for detectors that utilize it special capabilities of current availability, staff experienced in installing and operating physics detectors and a neutrino beam. Soudan is not suited for ultra-low background detectors because of its limited depth. It is not suited for the detectors with flammables or cryogens because of its single shaft. Building the large *ultra-K* water Cerenkov detector at Soudan would require a new primary shaft with the existing shaft used as a secondary escape. Available land exists for this option and the cost of the new shaft would be a small fraction of the total project cost for "ultra-K."

2.7 California-Nevada Border Horizontal Access Sites: The sites investigated in the California-Nevada border region include Charleston Peak, between Las Vegas and Pahrump in Nevada, Telescope Peak between Panamint Valley and Death Valley in California, Mount Tom and Mount Morgan, west of Bishop CA and Boundary Peak in the White Mountains almost directly on the California-Nevada border. It appears possible to achieve depths of 6,000 mwe or more with horizontal or slightly inclined adit lengths of 6,000 to 10,000 m. The Mt. Tom/Mt. Morgan site has an existing, unused mine that allows a detailed investigation of the geology without additional drilling. More information about these sites is presented in Appendix D.

3. Evaluation Factors

The Sub-Committee used its collective experience in performing nuclear and elementary particle physics experiments, including underground experiments, as well as its observations during site visits to existing laboratories to develop a set of evaluation factors that can be used to assess the potential of various sites. Clearly, some of the factors are much more important than others. The weights assigned to the various factors by different people will vary based on individual experiences, tolerance for risk and general approach. The Sub-Committee also believes that assessments on each factor can be combined in different ways—that is, additively or multiplicatively. Indeed, some factors should likely be combined one way and other factors should be combined another way. Regardless of these concerns, the Sub-Committee used assessments with respect to these factors to reach the conclusions that are reported in Section 4. The methodology issues lead to reliability estimates on the conclusions that are also discussed in that section.

The recommended evaluation criteria include the following 28 factors collected into 11 groups:

Group 1: Construction Costs—access, underground halls, outfitting mechanical/electrical systems, installing detectors
Group 2: Facility Operating Costs
Group 3: Risk—environmental/permitting, rock/salt structural integrity, seismic, mechanical systems
Group 4: Management—scientific, site operations, ownership/sharing
Group 5: Depth
Group 6: Neutrino Beam
Group 7: Time to Detector Installation
Group 8: Outreach Possibilities
Group 9: Local Awareness and Support
Group 10: Laboratory Context—cost of living, climate, travel to laboratory area, commuting to laboratory, local universities, ease of access, local industrial infrastructure, scientific environment
Group 11: Suitability for Detectors—ultra-low background, flammables and cryogens, “ultra-K” large water Cerenkov detector

3.1 Underground Costs: Both capital and operating costs are clearly important criteria in site selection and design of an underground science laboratory. During the site evaluation process, the Sub-Committee developed some general understandings of cost trade-offs for underground laboratories, which are reported here. Appendix C is a comparative table of the four principal candidate sites of their shielding depth and estimated costs.

(a) Capital or construction cost: The up-front cost of building a laboratory depends on a number of factors including (1) existing physical plant, if any, (2) whether the laboratory is built in rock or salt, (3) the quality of the ground, (4) the size of equipment that can be used, (5) the amount of materials handling required and (6) the cost, skill and availability of labor.

An *existing physical plant* is advantageous for a number of reasons, even if the laboratory is primarily built new. Existing access permits direct inspection of the ground quality without extensive test boring programs. An existing access has generally established a history of permitting for the site, as well a public perception that heavy construction on a site is expected. Existing access can be renovated, generally at less cost than new construction. Even if not renovated, an existing access can provide a secondary egress for safety or a ventilation access, reducing or eliminating the need for these features in new construction. Finally, since up-boring of a shaft is generally cheaper than down-boring, an existing access can reduce the cost of new shaft development.

There are some cost disadvantages associated with existing access. These include possibly antiquated mechanical systems that might require substantial maintenance or updating and buildings that need to be removed; other closure issues associated with shrinking the size of the existing underground physical plant to a needed and efficient size, including the cost of sealing off unused areas and pumping from a larger than necessary physical plant; legacy environmental issues and a need for workforce re-education and re-training to adapt from mining to civil construction.

Unit volume excavation costs in *salt* are approximately 3 to 5 times less than construction costs in *rock*. Salt is generally excavated using continuous grinders that are able to loosen enormous quantities of salt per person-hour worked. The density of salt is about 20% less than the density of rock, resulting in lower materials handling costs. In some locations, excavated salt can be sold, while excavated rock is generally at best given away, reducing disposal costs. Salt deposits are dry, so water handling is not required. Salt also exhibits plastic flow and pure salt does not generally have faults.

Ground quality affects construction costs in a number of different ways. The best ground is homogenous, high compressive strength rock or pure halite or anhydride beds without clay or rock inclusions. Areas with ore generally have heterogeneous rock and are less desirable. Areas that have been mined or have fractures or faults or inclusions have inhomogeneous stress fields and are more difficult both for design and construction. The poorer the ground, the more ground support is required. This ground support in the form of bolts, mesh and/or shotcrete increases both project cost and time.

Project cost is also affected by the *size of equipment* that can be used for excavation and transportation of muck and the *amount of materials handling* that is required. Labor typically represents about 40% of total project cost. Larger equipment can increase worker productivity and reduce labor cost. Each transfer of excavated rock or muck from one conveyance to another also increases cost.

Since labor is a significant cost, the *cost, availability and productivity of labor* are all important factors. Under the Davis-Bacon Act, labor costs are determined by the U.S. Department of Labor for each type of worker in each geographic area. A shortage of labor can increase costs through delay. Although, in principle, such delay costs to the contractor, in reality, contractors who are losing money seek to recover some of these losses from owners in a variety of ways. Well-trained and motivated workers and efficient management can also reduce project costs. The relatively high mobility of workers in the United States may limit the effect of these factors.

The cost of excavating *shafts* is approximately two to three times the cost of excavating *adits, drifts or tunnels* of similar cross-section and length. This cost primarily results from the materials handling problem. When rock or other material is loosen by blasting or continuous mining in a tunnel project, the loose material or muck can be easily scooped up with a front-end loader and placed on a conveyer or in a skip or dump truck for disposal. This method applies to downgrade tunnels, providing the slope of the excavation is not too large. When material in a down-bored shaft project, it is difficult to pick up and move. One exception is when the bottom of a new shaft is accessible via another shaft. Then, the muck can be pushed down a bored hole and retrieved using heavy equipment at the bottom. Another more efficient alternative is to drive a shaft upward—a so-called raise. This approach also facilitates automated mucking.

The cost of tunnels and shafts can be as much as doubled by *water infiltration* along the entire length. Water infiltration occurs in fractured ground conditions. Progress by either tunnel boring machine (TBM) or drill-and-blast methods is slower in fractured ground due to rock support issues. Furthermore, tunnels and shafts with water infiltration generally require watertight linings that also slow the progress of the work. In many cases, water infiltration and the resultant linings are only an issue for a fraction of the tunnel or shaft length—perhaps 10%—and the costs are reduced proportionately.

The excavation costs for *laboratory caverns* can vary by as much as a factor of two with lower costs for horizontal access. Generally, horizontal access permits use of larger equipment, which results in higher labor productivity, as discussed earlier. Secondly, horizontal access generally reduces materials handling because muck can be directly loaded into over-the-highway dump trucks and taken from the excavation site to a disposal area with no further handling. A vertical access facility often requires moving muck with underground transport, shifting it to a vertical skip and then moving the muck to long distance transport on the surface.

(b) Operating cost: Over a 20-year project lifetime, the laboratory operating costs are likely to exceed the capital costs. In general, the operating costs depend on the number, size and complexity of mechanical and other systems. These systems typically include: hoisting (in vertical access laboratories), ventilation, pumping (in vertical or downward-sloping horizontal access laboratories), cooling (depending on electrical load and rock temperature), electrical and security. These costs for a laboratory alone—not including the detectors' operating costs—are likely to amount to 5-10% of the capital cost per year. Because vertical access laboratories have more systems than horizontal access laboratories, the operating costs for a vertical access laboratory could be two to three times higher than for horizontal access. Local wage scales will certainly affect operating costs.

3.2 Construction Cost Factors

3.2.1. Construction Cost for Access: This factor includes site acquisition costs and costs for renovation and construction of shafts, adits, roadways, hoisting mechanisms or any other infrastructure required for both laboratory construction and ongoing physics access to the actual laboratory sites. Essentially, this item includes all capital costs other than costs specifically included in Factors 3.2.2 and 3.2.3 described below.

Gran Sasso: Horizontal vehicular tunnel access mostly built as highway project
Kamioka: original access via 7 km mine rail adit built for mining; current main access through single-lane vehicle adit
CUNL: Existing access for small or shallow detectors. New shaft required for access to the maximum 3,200 mwe level
Homestake: Proposed plan would renovate and extend one shaft in Phase 2 of the project
San Jacinto: New horizontal tunnel is required
Soudan: Existing access for small detectors. New shaft would be required for "ultra-K" detector

3.2.2. Construction Cost for Laboratories: The Sub-Committee's Technical Criteria document described three laboratories as part of the conceptual plan for the USNUSL. This factor includes the cost of preparing cavities for these laboratories including excavation, rock/salt disposal, and rock bolting, shotcreting and other procedures required to prepare clean, stable but empty caverns for detectors.

Gran Sasso: 3 laboratories, each approximately 20 m by 100 m by 20 m high built by drill-and-blast techniques with muck removal through highway tunnel; hard limestone rock; horizontal access
Kamioka: Super-K cavity holds approximately 50,000 m^3 of water of water and Kamiokande cavity (now housing KamLAND) approximately 5 times smaller; hard rock; horizontal access
CUNL: Salt; vertical access
Homestake: Hard rock; vertical access
San Jacinto: Hard rock; horizontal access
Soudan: Hard rock; vertical access

3.2.3. Construction Cost for Lab Mechanical Systems (Outfitting): In a typical underground laboratory, the cost for outfitting may nearly equal the cost for construction. Outfitting includes electrical power distribution, HVAC systems, life safety systems, general-purpose rigging and detector support systems, networking and communications systems and any other systems required to convert empty space into an efficient physics laboratory. Outfitting costs will vary from one site to another depending on costs of materials, prevailing wage rates and site properties such as ambient rock temperature that affects HVAC systems and method of egress that affects life safety systems. Davis-Bacon Wage Index (DBWI) computed as (1 electrician + 0.5 boilermaker + 1 equipment operator + 1 concrete finisher) normalized to Soudan as 1.00. The high level of integration in the American economy may reduce the effects of local wage variations.

Gran Sasso: Horizontal access
Kamioka: Horizontal access
CUNL: Vertical access, DBWI=0.80
Homestake: Vertical access, DBWI=0.63
San Jacinto: Horizontal access, DBWI=1.21
Soudan: Vertical access, DBWI=1.00

3.2.4 Construction Cost for Detector Installation: The cost of installation varies from detector to detector but it is at least 10 percent of a total detector cost and, in some cases, may be more than 20 percent of the total cost. Installation may also be a significant factor in the time required from approval of an experiment to the first physics publication. In some cases, installation costs are understated, because post-docs or graduate students perform a significant amount of installation work. Some sites may have lower installation costs or shorter installation times than other detectors because of ability to bring equipment to the laboratory in larger or heavier units or because of lower installation labor costs.

Gran Sasso: Horizontal access for large equipment and sub-contractors; large halls with bridge cranes provide adequate room for staging and good materials handling capability
Kamioka: Horizontal access for moderate-sized equipment and sub-contractors; limited staging area
CUNL: Large, modern hoist currently exists to 2000 foot level
Homestake: Access for detector installation is presently limited but improves after hoist and shaft upgrading in Phase 2
San Jacinto: Horizontal access for large equipment and sub-contractors
Soudan: Installation efficiency for “ultra-K” detector improves after construction of new shaft

3.3 Operating Cost

The operating cost of a site is the expenditure required for site for maintenance and depreciation of the site infrastructure not including the specific costs of operation of any detectors. Operating costs for sites will vary depending on prevailing wage rates and the extent and complexity of the mechanical systems required by the site. Sharing the site with another entity that contributes to operating costs for common access or other mechanical systems may reduce laboratory operating costs.

Gran Sasso: Maintenance of access mostly by *autostrada* agency; horizontal access requires fewer mechanical systems
Kamioka: Access shared with mining company; horizontal access requires fewer mechanical systems
CUNL: Vertical access and ventilation systems shared with waste repository; pumping and cooling not required
Homestake: Vertical access; science is sole user of all systems including access, pumping, ventilation and cooling
San Jacinto: Horizontal access; science is sole user of ventilation and cooling systems
Soudan: Vertical access; share access and pumping with state park; mostly natural ventilation

3.4 Risk Factors

3.4.1 Permitting and Environmental Risk: There is considerable experience both in United States and abroad of delay and cost escalation in major projects, including scientific projects, due to permitting and/or environmental considerations. There is no doubt that USNUSL must operate in a safe and environmentally conscious manner. This factor suggests more the time and expense required at various sites to determine what is safe and environmentally sound. It also includes an estimation of the time and cost that might be required to ascertain whether a particular detector containing exotic materials could be installed at USNUSL.

Gran Sasso: Laboratory expansion has been delayed for years over environmental concerns
Kamioka: Historic mining area; shared location between science and active mining
CUNL: Extensive permitting history and experience; shared mission site with primary focus on transuranic waste disposal
Homestake: Liability release legislation required; historic mining area; single purpose site after conversion
San Jacinto: Large nearby population; single purpose site
Soudan: Historic mining area; University of Minnesota issues own building permits

3.4.2 Rock/Salt Risk: This risk factor includes multiple considerations relative to the risk of capital and operating cost overruns due to unexpected rock or salt conditions. The sites vary considerably in the degree of knowledge of actual rock conditions at the proposed USNUSL site. The deep sites have high lithostatic pressures and laboratory construction could encounter considerable difficulty, even in sites with relatively well-known rock conditions. The risk in salt is different and is related mostly to possible unexpected costs due to detector or support structure misalignment as a result of salt creep or a possible need to re-mine cavities

Gran Sasso: Hard limestone rock; *autostrada* tunnel permits access to rock in order to choose optimal laboratory site, but major aquifers present
Kamioka: Hard rock; extensive mining development permits access to rock in order to choose optimal laboratory site
CUNL: Extensive salt layer with clay layer intrusions
Homestake: Multiple rock types; extensive mining development permits access to rock in order to choose optimal laboratory site
San Jacinto: Igneous rock batholith; not feasible to core much of access tunnel prior to construction
Soudan: Multiple rock types; schistose

3.4.3 Seismic Risk: Although engineering can control seismic risk, there is an additional cost required to build USNUSL and install detectors in a seismically active region. In addition, there is a risk of a more intense than expected earthquake or an engineering or installation mistake that leads to failure in an earthquake of expected magnitude.

Gran Sasso: Active seismic area; the highway tunnels traverse two vertical faults and follow under a third horizontal fault.

Kamioka: An active seismic region with mining-related local seismic activity
CUNL: No seismic activity in recent geologic history
Homestake: No seismic activity in recent geologic history:
San Jacinto: San Jacinto and San Andreas faults within 25 km. Both faults are major and currently active.
Soudan: No seismic activity in recent geologic history

3.4.4 Mechanical Systems Risk: Sites with more extensive HVAC, hoisting or other machinery have an operating cost risk due to the possibility of failure of significant mechanical systems. Such failure could entail significant emergency operating expenditures and/or significant lost time in access to the USNUSL. While the importance of this factor is likely correlated with the magnitude of the operating cost, the Sub-Committee deems this risk factor of sufficient importance to include it separately.

Gran Sasso: Horizontal access; only major mechanical system is ventilation
Kamioka: Horizontal access; major mechanical systems are ventilation and radon de-gasification
CUNL: Hoisting and ventilation systems; risk shared with waste repository facility
Homestake: Hoisting, ventilation, pumping and cooling systems
San Jacinto: Ventilation and cooling systems
Soudan: Hoisting and pumping systems; risk shared with state park

3.5 Management

3.5.1 Scientific Management: While the ultimate decisions about scientific management will be made in discussion with the funding agencies, this issue was discussed during several of the site visits. The usual national laboratory model, both in the United States and abroad, centers on an established scientist as the Scientific Director. A Board of Directors appoints the Scientific Director, after extensive consultation in the scientific community and with the funding agencies. The Board members are themselves appointed by important national institutions. A Program Advisory Committee, consisting of a broad range of scientific experts, advises the Scientific Director. The quality of the laboratory program is reviewed by a Visiting Committee, which includes expert scientists, who are mostly not involved in the day-to-day activities of the Laboratory. Those scientists who are directly involved in the Laboratory form a Users' Committee to represent their ideas and concerns.

Gran Sasso: Management by INFN
Kamioka: Management by Institute for Cosmic Ray Research (ICRR)
CUNL: LANL (University of California), Department of Energy, New Mexico State University, University of New Mexico plus others
Homestake: University or other consortium including the South Dakota School of Mines & Technology
San Jacinto: University of California, particularly UC Irvine, plus others
Soudan: University of Minnesota plus others

3.5.2 Site Operations Management: Management of site operations may require somewhat different skills from scientific management. While in the usual national laboratory model, site operations form a distinct division that ultimately reports to the Scientific Director, other models are possible. In particular, some sites have existing operational structures with extensive knowledge and experience in operating the site. These human resources are important and care must be taken to retain and enhance them. In general, civil construction and laboratory operation are different enough from mining operations and ore extraction that re-training and re-deployment of existing staff may be advisable.

Gran Sasso: Site operations management by INFN
Kamioka: Mining operations and site work performed by Mitsui Corporation
CUNL: Site operations management by Westinghouse TRU Solutions, the existing management and operations contractor to the DOE
Homestake: Site operations by existing staff following re-orientation and re-training
San Jacinto: Assemble new staff under University of California management
Soudan: Augment existing physics operational staff

3.5.3 Ownership and Site Sharing: The sites considered differ in whether use of the site is exclusive to USNUSL or use of the site is shared with another entity. Sharing has an advantage in reducing operating costs, but it has a disadvantage in potential access or other conflicts. Sharing is particularly disadvantageous if the use other than scientific research has priority. This factor also considers whether the management entity for USNUSL has sufficient ownership and/or easements to provide for future expansion or modification of the site capabilities.

Gran Sasso: Access shared with *autostrada*, but otherwise dedicated site
Kamioka: Mining activities in the past are now sharply curtailed
CUNL: Ownership by DOE; shared use with waste repository
Homestake: Ownership by State of South Dakota; exclusive science use
San Jacinto: Ownership by State of California; exclusive science use
Soudan: Ownership by State of Minnesota; shared use with state park

3.6 Depth

Detectors are placed underground primarily to lower backgrounds due to the direct and indirect effects of cosmic rays. Direct effects include the passage of muon and muon-generated particles through the detector. Indirect effects include radioactivity generated by spallation and nuclear de-excitation following the passage of a muon or muon-generated particle. Although the sensitivity of particular detectors to depth varies, for most detectors deeper is better down to depths at which neutrino-generated muons dominate the muon flux. Depths of more than 7,000 mwe are probably not important but 7,000 mwe is clearly better than 5,000 mwe. For the same vertical depth, a site with relatively flat overburden has integrated flux equivalent depth about 10 percent greater than that of a mountain. It is possible that some detectors would prefer shallower depths, either to use remnant muon flux for testing or calibration or because of somewhat lower costs associated with construction and operation at shallower depths. For this reason, a site that offers a variety of depths, including one or more deep locations, is likely preferably to a site with a single, fixed depth.

Gran Sasso: 3,800 mwe; mountain; single depth
Kamioka: 2,700 mwe; mountain; single depth
CUNL: 1,600-2,000 mwe now; 3,200 mwe later with new shaft; flat overburden; halite and anhydride overburden has lower density but higher atomic number than rock
Homestake: 6,700 mwe most likely depth; flat overburden; most feasible depths include 700 mwe, 1,500 mwe; 2,100 mwe; 3,100 mwe; 3,400 mwe; 4,500 mwe; 7,200 mwe
San Jacinto: 6,500 mwe; mountain; range of depths can be selected by laboratory location
Soudan: 2,200 mwe; flat overburden; depth measured using muon flux

3.7 Neutrino Beam

The study of neutrinos is an important feature of underground, low-background physics. Current thinking is that the “ideal” baseline for a neutrino oscillation experiment is approximately 2,500 km.

Gran Sasso: 750 km to CERN
Kamioka: 300 km to KEK
CUNL: 1,750 km to FNAL; 2,900 km to BNL
Homestake: 1,290 km to FNAL; 2,530 km to BNL
San Jacinto: 2,610 km to FNAL
Soudan: Beam from FNAL currently under construction — 740 km to FNAL; 1,720 km to BNL

3.8 Time to Install First Detectors

Although the time scale for accelerator and non-accelerator nuclear and particle physics experiments has become increasingly long, there is value to achieving the first physics results as early as possible after authorization to establish a USNUSL. This criterion clearly favors existing over new sites, but the Sub-Committee believes that its importance justifies its inclusion.

Gran Sasso: Currently operating
Kamioka: Currently operating
CUNL: Small detectors now; medium detectors in 6 months; large detectors at new, deeper level in 3 years
Homestake: Small detectors now, larger detectors in 1-3 years (new larger chambers in 1-2 years, new hoist in 2-3 years).
San Jacinto: 5 years
Soudan: Small detectors now, *ultra-K* in 5 years

3.9 Outreach

The American scientific community has a clear responsibility to America's citizens to inform them about the goals and progress of scientific research. The science likely to take place at USNUSL is exciting fundamental science that can be well communicated to both the general public and to diverse student and other groups. This factor represents an estimation of both the outreach potential of a particular site based on the size of the local permanent and vacationing population and the perceived quality of any outreach plans described by the site advocates.

Gran Sasso: Good public visibility regionally and nationally; frequent tours by school and other groups
Kamioka: Good public visibility regionally and nationally; tours by school and other groups
CUNL: 500,000 tourists per year visit Carlsbad Caverns; NMSU outreach center program in Carlsbad
Homestake: 3 million tourists per year in Black Hills
San Jacinto: 300,000 residents in Coachella Valley; 15 million people live within 3-hour drive
Soudan: Ongoing experience with outreach programs; history of coordination with state park; 40,000 tourists per year

3.10 Local Support and Awareness: The siting of the USNUSL is clearly, in part, a political process. Awareness and support by local citizens, governments and institutions is clearly an important aspect of the siting process. Local governments and/or institutions can provide some funding, especially in the early stages of the laboratory development. In addition, the USNUSL will need to meet local regulations and codes with respect to construction, transportation of materials and other operational aspects. The site visits have also suggested to the Sub-Committee that local political support as reflected through State Congressional delegations will likely have a real effect on the progress of USNUSL.

Gran Sasso: Strong support by some municipalities and groups and resistance by others.

Kamioka: Good community awareness and support within local limited population
CUNL: Strong local and political support; growing public awareness
Homestake: Strong local and political support; extensive public awareness
San Jacinto: Strong local support; limited public and political awareness
Soudan: Strong local support; extensive public awareness

3.11 Site Environmental Factors

3.11.1 Cost of Living: This factor affects USNUSL through the cost to maintain graduate students, post-docs and visitors at the USNUSL site. Although this cost does not accrue directly to USNUSL, it likely affects the ability and willingness of collaborating institutions to maintain people on site for detector installation and operation. The cost for each site listed below includes a two-week stay at a moderately priced hotel (for example, Day's Inn), airfare from Chicago and meals).

CUNL: $1,547
Homestake: $1,533
San Jacinto: $2,754
Soudan: $1,365

3.11.2 Climate: People like to live and work in nice climates. This factor addresses purely the meteorological climate.

CUNL: 30° to 90° F; semi-arid
Homestake: 20° to 70° F; semi-arid
San Jacinto: 60° to 100° F; desert
Soudan: -20° to 75° F; boreal forest

3.11.3 Travel to Sites: Scientists will visit the USNUSL from various parts of the United States and the world. This factor addresses access to the laboratory, mostly by commercial air service. It includes flight time, number of connections, frequency of service, main line vs. commuter service, cost of travel and driving time required from the nearest airport to the site.

Gran Sasso: About 2 hour drive (depending on traffic) from Rome Leonardo da Vinci Airport
Kamioka: About 1 hour drive from Toyama Airport. Flights to Toyama leave only from Tokyo Haneda Airport, while flights from U.S. to Tokyo arrive at Narita Airport. Airport change in Tokyo requires at least 2 hours
CUNL: Carlsbad Airport is 1/2 drive from laboratory, but has only commuter service; Midland (2 hour drive) and El Paso (3 hour drive) have jet service
Homestake: Rapid City Airport is 1 hour drive and has jet service to Minneapolis and commuter service to Denver and Salt Lake City
San Jacinto: Palm Springs Airport is 15 minute drive and has jet and commuter service
Soudan: Hibbing Airport is 1 hour drive and has commuter service; Duluth Airport is 1.5 hour drive and has jet service to Minneapolis and Chicago

3.11.4 Commute Time: Although ease of travel to the USNUSL is important, the time for a typical worker or physicist to reach her or his workplace is also important. People need and choose to live where housing and services such as stores, health care, schools and other goods and services are available. In some sense, this factor is a measure of the driving time between USNUSL and the nearest supermarket.

Gran Sasso: Assergi to the Laboratory is a 30 minute round trip
Kamioka: Mozumi to the Laboratory is a 30 minutes round trip. Most long-term visitors live nearer Toyama, resulting in a 1 to 2 hour round trip.
CUNL: 1 hour round trip
Homestake: 15 minute round trip
San Jacinto: 30 minute round trip
Soudan: 15 minute round trip

3.11.5 Local Universities: USNUSL ideally will have a rich intellectual and academic life and provide an environment that nourishes physics innovation, both experimental and theoretical. Proximity to one or more strong research universities is clearly an asset.

Gran Sasso: Nearest universities involved in laboratory are in Rome
Kamioka: Strong involvement from universities in Tokyo and Sendai
CUNL: University of Texas El Paso is 3 hours away; New Mexico State University in Las Cruces is 4 hours away; University of New Mexico in Albuquerque is 5 hours away
Homestake: South Dakota School of Mines and Technology is 1 hour away
San Jacinto: University of California Riverside is 30-minute drive; UC San Diego, UC Irvine, UCLA, Caltech, USC and many Cal State campuses are within 2-3 hours (depending on traffic)
Soudan: University of Minnesota-Duluth is 90-minute drive; UM-Twin Cities is 4-hour drive

3.11.6 Ease of Personnel Access: The Sub-Committee believes that perceived ease of personnel access to the laboratory is important both as a substantive factor and as a quality-of-life factor. Ideally, the laboratory is available 24 hours per day, seven days per week. At best, access to the laboratory also requires no advance notice, requires no waiting, takes a minimal amount of time and allows personnel to bring small amounts of equipment with them. For safety and security reasons, access should be controlled and monitored, but the control/monitoring system should be as reliable and automatic as possible and impose as little as possible burden on authorized staff while keeping out unauthorized people and maintaining a real-time log of the identity and location of personnel underground.

Gran Sasso: Possible to drive in via *autostrada* tunnel and park at laboratory, although most people use shuttle bus
Kamioka: Possible to drive-in via horizontal access and park at laboratory
CUNL: Vertical access; some limitations on waste hoist access; 45-day index notification period required before first visit by non-U.S. national
Homestake: Vertical access, automated after renovation
San Jacinto: Horizontal access; underground parking
Soudan: Vertical access, automated with new hoist

3.11.7 Local Industrial Infrastructure: The National Underground Science Laboratory requires both goods and services that are similar to those used in heavy industrial and natural resource recovery operations. Spare parts may be needed on short notice for equipment such as front-end loaders, drills, forklifts and other materials handling devices. Contract services may be needed for specialty welding, machinery repair and mechanical and electrical system maintenance. This factor addresses the extent to which such goods and services may be available in the vicinity of the laboratory site.

Gran Sasso: Rome is about a 2-hour drive
Kamioka: Mining area; Toyama is a seaport with good industrial infrastructure
CUNL: Historic and current mining and hydrocarbon extraction area; 30 minute drive to Carlsbad, 2-3 hours drive to Midland and El Paso
Homestake: Historic mining area with tourism as current main activity; 1 hour drive to Rapid City
San Jacinto: Primary local industries are tourism and agriculture; 15 minutes to Palm Springs, 30 minutes to Riverside, 2-3 hour drive to Los Angeles
Soudan: Historic and current mining area; 60-90 minute drive to Mesabi Range mining cities and Duluth

3.11.8 Scientific Environment: graduate students will do much of the work of installing and operating detectors at the NUSL and post-doctoral research associates living at the Laboratory for extended periods. This factor relates to the scientific environment for these people. It assesses to what extent graduate students, while at the Laboratory can, pursue their general scientific and academic development, not just their skill at a particular project.

Gran Sasso: Universities in Rome and L'Aquila
Kamioka: University in Toyama, but not active in Laboratory. Data analysis and computing center in Mozumi
CUNL: Several campuses 3-5 hour drive
Homestake: South Dakota School of Mines and Technology is 1-hour drive
San Jacinto: Access to UC Riverside, UC Irvine, Cal State San Bernardino and universities in Los Angeles
Soudan: University of Minnesota Duluth is 90-minute drive

3.12 Suitability Factors for "Typical" Detectors Described in the "Criteria" Document

3.12.1: Suitability for Detector A (Ultra-Low Background)

Gran Sasso: Moderate Depth
Kamioka: Moderate Depth
CUNL: Shallow to moderate depth
Homestake: Very deep
San Jacinto: Very deep
Soudan: Shallow depth

3.12.2 Suitability for Detector B (Large Inventory of Flammables) and Detector C (Large Inventory of Cryogens)

Gran Sasso: Horizontal access permits direct deliveries of materials without transfer
Kamioka: Horizontal access permits some direct deliveries of materials without transfer
CUNL: Vertical access; approved-Environmental Assessment for these materials
Homestake: Vertical access
San Jacinto: Horizontal access permits direct deliveries of materials without transfer
Soudan: Not relevant unless new shaft is built for “Ultra-K” detector

3.12.3 Suitability for Detector D (Ultra-K Water Detector)

Gran Sasso: Horizontal access facilitates large excavation; hard rock environment
Kamioka: Horizontal access facilitates large excavation; hard rock environment
CUNL: Vertical access; salt environment; currently no water at site
Homestake: Vertical access; hard rock environment; shaft renovation will facilitate excavation of large quantities of rock
San Jacinto: Horizontal access facilitates large excavation; hard rock environment
Soudan: Vertical access; hard rock environment; new shaft required to facilitate large excavation

4.0 Analysis and Assessment of Observations

The Sub-Committee presents the following analysis and assessment of its observation for the purpose of informing the full Committee in its discussions.

4.1 The Sub-Committee has carefully examined all known information about each of the four sites studied in detail—Carlsbad UNL, Homestake, San Jacinto and Soudan—in order to determine the possible existence of a "show-stopper" at any site. A "show-stopper" is a factor that cannot be addressed by good engineering design or other good practices and which has such negative consequences that it would be impossible to do important and competitive science experiments at that site. The Sub-Committee finds no such "show-stopper" factors. In other words, the Sub-Committee believes that all four sites are feasible as scientific laboratories.

4.2 The Sub-Committee believes that a national underground laboratory in the United States should facilitate a new generation of detectors with higher sensitivities than what can currently be achieved. One important factor in achieving higher sensitivity is reduction of background due to radiation. The Sub-Committee believes that backgrounds due to natural radioactivity at any site can be readily reduced by a good choice of materials and by appropriate shielding against ambient radioactivity. The Sub-Committee further believes that radioactivity due to radon at any site can be controlled using straightforward techniques such as additional ventilation, water degasification and impermeable polyurethane coatings (Mine Guard or Urylon). Direct and indirect cosmogenic radioactivity, however, can only be reduced by extreme depth. For that reason, the Sub-Committee believes, based on recent experience with the SNO detector, that extreme depth (>6,000 mwe) is now required to achieve otherwise reachable sensitivities in double beta decay and solar neutrino detectors. In addition, the Sub-Committee believes that many detectors, including an "ultra-K" detector, would benefit from depths at least as deep as Gran Sasso, that is, 3,800 mwe. For these reasons, the Sub-Committee suggests that strong consideration should be given to establishing a primary site for the National Underground Laboratory at a location that can feasibly provide access to depths >4,000 mwe. Access to multiple depths, both shallow and deep, is also likely a positive factor. Other sites have been used for previous detectors and will likely continue to be used for some detectors for a variety of reasons. Of the particular sites considered by the Sub-Committee, only the Homestake and San Jacinto sites meet this condition regarding depth.

4.3 The Sub-Committee has attempted to assess the degree of certainty to which one might determine that one site is "better" than another. With the exception of the depth factor described above, the Sub-Committee believes that an ordinal ranking of sites with a high level of certainty is difficult to achieve. The Sub-Committee has found among its members a high level of congruence in the ordinal ranking of sites with respect to each factor. However, there is a wider range of opinion with respect to the relative importance of each factor. Some of the largest variations of this type are associated with risk factors and reflect wide ranges of individual tolerance for risk. This variance is particularly clear in the assessment of what weight should be given to major, project-stopping risks, even if the probability of an adverse event is small. There is also a range of opinion on whether factor rankings should be combined additively or multiplicatively, that is, whether a single important factor should have a large effect on the overall ranking. The Sub-Committee suggests that a choice among sites may require factors other than those described here, such as the success probability of various development scenarios for the various sites.

4.4 *Carlsbad Underground National Laboratory (CUNL):* The CUNL site benefits from a substantial past and ongoing investment by the United States resulting in an excellent human resource and physical infrastructure. The salt ambient at CUNL is also easy and cheap to dig and offers dry environments with low radioactivity due to uranium, thorium and radon. The site advocates believe that "salt creep" can be addressed by good engineering design and by techniques such as "pre-mining" or "re-mining." For these reasons, CUNL has hosted and will likely continue to host a variety of important detectors. Indeed, for quick turnaround for detector development and prototyping in a low background environment, CUNL is currently the best site in the United States in many respects. As indicated above, the Sub-Committee believes that the depth factor alone suggests that CUNL should not be the primary site for a national underground laboratory. However, the Sub-Committee encourages the DOE and Westinghouse TRU Solutions to continue its present efforts to support important underground science, including crucial detector research and development and prototyping studies.

4.5 *Homestake Underground National Laboratory:* The Sub-Committee believes that Homestake offers an excellent site for an underground national laboratory. The existing human resource and physical infrastructure are outstanding. The commitment of the State and people of South Dakota to this project is impressive. The Sub-Committee cautions, however, that the value of the Homestake site is time-dependent. The Homestake Mining Corporation has publicly indicated that it plans to close the mine and terminate employment for many of its staff no later than the end of 2001. Although a severance package will tend to keep staff members on site until they are laid off, site advocates have noted that significant staff erosion can be expected to begin when schools close in June 2001 and to continue over the next six months. At some point, if plans for an underground laboratory appear uncertain, the Homestake Mining Corporation, as part of its normal closing process, might take actions that would diminish the value of the physical assets at Homestake as a basis for a national underground Laboratory. The Sub-Committee believes that if the full Committee should designate Homestake as the primary site, the Committee should also strongly encourage site advocates to pursue a time-sensitive plan that would minimize the possibility of deterioration of either the human or physical resources of this site. The Sub-Committee also notes that solving the indemnification issue may not be an easy or quick process.

4.6 *Mount San Jacinto:* The Sub-Committee believes that San Jacinto offers an excellent site for a national underground laboratory. The proposed horizontal access at San Jacinto provides long-term advantages in cost of laboratory excavation, installation of detectors and ongoing operating costs. The Sub-Committee was impressed by the strength of local support among civic leaders who were informed about the project. The Sub-Committee notes, however, that San Jacinto is qualitatively different from the other sites not just in its horizontal access, but also in the number of people who live nearby and in the absence of a recent mining tradition at the site. Although the large local population and even larger population within 150 km provides significant outreach potential, as well as urban amenities that make the site attractive, it also increases the efforts required to educate potential neighbors about the project. Native American traditions with respect to Mt. San Jacinto and the natural beauty of the region further complicate this task. Both the National Environmental Protection Act (NEPA, which applies at all sites) and the California Environmental Quality Act (CEQA) apply to the Mt. San Jacinto site. These acts provide an adjudication process, that is, there is a way to determine whether and under what conditions, an underground science laboratory could be built at Mt. San Jacinto. The Sub-Committee believes that such a process, if well managed, might lead reasonably quickly to findings of no impact and requirements of relatively small mitigation. This belief rests on the project design, which places the entire laboratory underground, except for a well-camouflaged portal and roadway, requiring an aggregate of about one acre of land. All other surface structures are placed in already urbanized areas of Palm Springs and are irrelevant to the environmental issue. The Sub-Committee suggests, because of the quality of the San Jacinto site, efforts should continue to increase public awareness about the project and to begin the NEPA and CEQA processes, even if the full Committee places first priority on another site.

4.7 *Soudan Underground Laboratory*: The Soudan Laboratory particularly impressed the Sub-Committee in several respects. Soudan currently exists, has a highly-skilled, science-oriented support staff and has a track record of doing science for more than a decade. The Soudan Laboratory demonstrates the feasibility of renovating a mine into a world-class physics laboratory. Although smaller than Gran Sasso and shallower than a number of sites, Soudan continues to host important and competitive physics detectors. Indeed, the MINOS Far Detector and CDMS II make significant physics productivity at Soudan likely for at least another decade. These accomplishments are even more impressive because of the small size of the single shaft at Soudan. The Sub-Committee is also impressed by the outreach efforts at Soudan, particularly the construction of a visitor gallery for the MINOS Far Detector Laboratory and the plans to begin regular visitor tours of the Laboratory in cooperation with the State Park, beginning in Summer 2001. A further advantage of the Soudan site is its location as the target area for the Fermilab Main Injector neutrino beam. Despite these advantages, the Sub-Committee believes that the limited depth at Soudan suggests location elsewhere of the primary site for the national underground laboratory. The Soudan site will likely continue to provide a venue for significant detectors, especially those that do not require great depth and would benefit from the neutrino beam. In particular, the “ultra-K” detector, if constructed at Soudan, would both require and justify the cost of a constructing a new shaft to provide dedicated physics access, while retaining a connection to the State Park shaft for visitor access and a safety egress.

4.8 *Other Sites:* The Sub-Committee has identified additional potential sites in the vicinity of the California-Nevada border, that appear to offer possibilities for horizontal access and some of the other advantages of Mt. San Jacinto. A cursory investigation suggests that these sites may have fewer environmental concerns than the San Jacinto site, either because of small nearby populations and/or because of a local tradition of mining, either for ore or in connection with the Nevada Test Site. The Sub-Committee suggests, again regardless of the recommendation by the full Committee, that investigation of these sites should continue, at least to the point of determining whether there may be clear “show-stoppers” connected with any of them. A further discussion of these sites is included in the Appendix D.

4.9 *Summary:* The Sub-Committee’s analysis is reported to the full Committee in summary as follows: All four sites investigated in detail are acceptable. The depth factor alone justifies narrowing the site search to Homestake and San Jacinto. These two sites may well be equivalent within uncertainties, but the quality of the Homestake site is more time-dependent. Selecting between these sites likely requires consideration of other factors, such as the success probability of various development scenarios and tolerance for risk. With respect to Carlsbad UNL and Soudan, the Sub-Committee believes that underground science that exploits the special advantages of each of these sites will likely continue. The Sub-Committee also suggests continued study at an appropriate level of the California-Nevada border sites, to facilitate a deep alternative if both the Homestake and San Jacinto prove infeasible.

Finally, the Sub-Committee wishes to step outside the boundaries of its charge and make the following statement. “The case for a multi-purpose underground science laboratory is compelling. The technical considerations assessed by the Sub-Committee indicate that the project is feasible. Within one to five years, the United States can have a world-leading facility with unsurpassed depth to advance a wide range of important science that requires very sensitive detectors and very low background. The Sub-Committee believes this initiative should proceed on the fastest possible time scale.”

Appendix A: Glossary of Mining Terms

Addit: A horizontal or nearly horizontal tunnel with a single opening or portal. Addits end inside the earth. They are generally built for mining in regions with significant elevation variations.

Back: The ceiling of a tunnel or stope or the rock/salt immediately below this ceiling. When excavating a stope, the rock or salt nearest the back is generally excavated first. Ground support is then installed into the back before removal of the remaining rock or salt, which is known as the bench.

Bench: The rock or salt that remains after the back is excavated. The cost per unit volume for removing the bench is almost always less than the cost per unit volume for removing the back.

Bolt: A bolt is a high-tensile-strength steel rod that is inserted into a hole drilled into rock and then locked into place with either grout or a mechanical anchor. Bolting increases the tensile and sheer strength of rock.

Drift: A tunnel with no portals, that is, a tunnel that begins and ends underground.

Drill and Blast: The common excavation technique in which holes are drilled into rock and filled with high explosive, which is then detonated to excavate and pulverize the rock. The volume of blasted rock is typically 140% of the original rock volume.

Ground Support: Bolting, meshing or shotcreting, all of which are used to increase the tensile and sheer strength of the rock, to inhibit rock defoliation or to catch small pieces of rock that may defoliate.

Muck: Pulverized rock loosened by a mining operation that needs to be removed to leave a tunnel or a stope. “Muck” can also be used as a verb to describe the process of removing this rock.

Over-mining: The technique of compensating for salt creep by making cavities larger than the desired dimensions. This strategy implies reasonable initial knowledge about the desired lifetime of the cavity.

Portal: An opening to the outside environment at the end of an addit, tunnel or shaft.

Pre-mining: The technique of compensating for salt creep by mining a cavity, allowing the salt to creep for some time interval (generally months) and then trimming the cavity to the desired dimensions.

Raise: A short winze. Personnel raises are generally equipped with ladders rather than hoists. Rock raises are used for dropping rock to a lower level. The term raise is used because raises are usually bored upwards.

Re-mining: The technique of compensating for salt creep by periodically milling cavities to their original dimensions.

Salt Creep: The tendency for halites and anhydrides to exhibit plastic flow under lithostatic pressure. The amount of creep depends on the size of openings and the extent to which salt flow may be constricted by rock or facilitated by clay slip planes. Salt creep may be addressed by over-mining, pre-mining or re-mining. Rock support is generally ineffective at preventing salt creep.

Shaft: A vertical access that begins at ground level and ends within the earth. Shafts often have multiple compartments that are used for various purposes including personnel hoisting, rock or hoisting and piping and other utility access. Shafts are used for mining in regions where ground elevations are relatively uniform.

Shotcrete: Concrete that is sprayed onto rock using high pressure pumping systems.

Stope: A cavity, sometimes large, from which ore is extracted. In mining terms, underground laboratories are stopes. Stoping is the process of opening up a stope.

TBM: Tunnel boring machine. TBMs are used to bore long, horizontal or nearly-horizontal tunnels. Since the capital cost of a TBM is typically $10 million, they are not cost-effective for short tunnels.

Tunnel: Specifically, a tunnel is a cavity with a long horizontal or nearly-horizontal dimension and short dimensions at right angles to this long dimension that has an opening or portal at each end. More generally, a tunnel is the generalization of addit, drift and tunnel.

Winze: A shaft with no portal, that is, a shaft which begins and ends underground.

Appendix B: Criteria for Technical Evaluation of an Underground Laboratory Site

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1. Introduction

The selection of an underground laboratory requires the evaluation of a broad range of technical criteria. No site is likely perfect for even a single underground physics experiment. Site selection for a multi-purpose laboratory is even more difficult because the “best” site for one detector may not be the optimal choice for another, very different detector. The Technical Sub-Committee places a high priority on site properties that will facilitate significant, likely order of magnitude, sensitivity improvements in a wide range of low background experiments. Such improvements will probably result from one or more of the following: (a) increase in sensitive mass, (b) decrease in impurities, (c) more sensitive instrumentation and/or electronics and (d) more difficult to handle or more costly materials. The properties of a laboratory that will facilitate significant progress include: (a) fast, convenient access for personnel and instrumentation of varying size and weight, (b) large, clean, air-conditioned, well-illuminated experimental and support rooms with sufficient room for staging, assembly, monitoring and maintenance of large, complex detectors, (c) a range of rock depths at one or more sites, some of which are equal to or greater than those available elsewhere in the world and (d) a management plan and outreach strategy that will efficiently facilitate both the highest quality science and comprehensive public education and understanding.

The Gran Sasso Laboratory (LNGS) in Abruzzo, Italy provides both proposers and evaluators with a good reference point. LNGS provides an aggregate volume of 180,000 m at a depth of approximately 4,000 mwe. About half of the volume is contained in three large experimental halls, each with a cross-section of approximately 15 m by 15 m and a length of approximately 100 m. The remaining volume is provided in a variety of access and experimental tunnels, connecting and circumscribing the three large halls. LNGS provides good access for large and heavy instrumentation through horizontal vehicular tunnels capable of passing the largest highway trucks and trailers. LNGS is also clean, dry, at a comfortable temperature and humidity and supplied with abundant electrical power and communications. A new laboratory should represent a significant improvement over LNGS in as many attributes as possible with few, if any, compromises with respect to LNGS capabilities. To further assist proposers, we discuss here four possible prototype experiments, but these should be considered as simply illustrative of likely experimental requirements. The last of these examples is a megaton-scale liquid Cerenkov or scintillator detector optimized for both proton decay and neutrino physics. The compressed time scale of this study and the complexity of an “ultra-K” detector mostly limit consideration of this last detector to a “go or no-go” dichotomy. We expect to report only very preliminary estimates of feasibility and cost for this enormous detector at the various sites.

The strategy for this evaluation is to the extent possible to compare diverse sites on an equivalent basis. The obvious common denominators are physics capabilities and cost, both capital and operating. The trade-off between capital and operating costs for a particular site should assume that it will be possible to secure an initial capital outlay for building and/or renovating the site. Proposers should also assume that the initial investment will be sufficient to enable the laboratory to operate in an efficient manner and have a reasonable time to build a depreciation/replacement reserve for significant equipment maintenance. There are some factors, particularly those in the general category of “quality-of-life” that are not easily addressed in this approach. For those factors, we expect to report information for each site without extensive evaluation.

The Technical Assessment Sub-Committee believes that the four sites it is currently considering as well as any sites that may be proposed can be generally divided into one of two categories: deep and shallow. “Deep” is defined as access to depths substantially greater than those available at LNGS while “shallow” sites are limited to LNGS depths or less. The Sub-Committee further believes that physics considerations may well dictate that an optimal underground physics laboratory strategy for the United States should include access to a “deep” site. If so, two alternatives are obvious: (1) locate the laboratory at one site that has a range of depths available, including some that are “deep” or (2) locate the laboratory at one “deep” and one “shallow” site. Of the prototype detectors described here, the “ultra-K” detector would benefit the least from large depth. In addition, the lithostatic pressure at large depth might complicate construction of the large spans required for its enormous volume. The Sub-committee strongly recommends to proposers that they include plans and costs to reach the greatest depth that might be reasonably attainable at their sites, as well as describing plans and costs for locating the laboratories and other facilities at the greatest depth now available at their site, without substantial shaft, addit or drift development. For simplicity, we suggest that proposers assume Detectors A, B and C as described below are all at the same depth, although other, perhaps more optimal arrangements are of course possible.

The Sub-Committee also believes that a national underground physics facility must be designed and constructed to the standards of a long-term, human-occupied civil engineering project and not those of an operating mine. As much as possible, the entire facility, including shafts, addits, drifts and laboratories, should be dry, have a temperature of approximately 18° C and a relative humidity of less than 60 percent. Design and construction standards should include appropriate rock/salt excavation methodology and support measures; fire suppression, gas detection and other safety systems; and two independent accesses. Proposers should also consider designs that might build in refuge facilities at a relatively small cost, such as outfitting an isolated control room or pump room with fire stops and an independent air supply.

An important parameter in achieving a world-class facility is low background from radioactivity. Some experiments may require local shielding and/or increased ventilation in order to reduce background levels. The Sub-Committee is interested in data concerning radioactive backgrounds from uranium, thorium and potassium at each proposed site. Data concerning radon levels, both without and with forced ventilation and neutron fluxes would also be useful.

2. Detectors

This evaluation assumes installation in the laboratory of Detectors A, B and C described below. The evaluation of the feasibility of the megaton-sized Detector D is done separately. To facilitate detector assembly and installation and to provide for future laboratory flexibility, proposers should assume that Detectors A, B and C will be each installed in “general-purpose” laboratory hall with rectangular-solid volumes and domed ceilings to distribute lithostatic pressure. Thus, the laboratory design should include three rooms, each of width 20 m by length of 100 m by height of 20 m. The design for Detector D should be in the “mailbox” geometry with width and height of 50 m each and length of 200 m. Detector D must be located for safety reasons below the grade level of its access drifts. Access drifts between laboratories should be as short as possible and should be of cross-section of at least 8 m by 8 m to facilitate use of space in one laboratory as a staging area for a detector in another laboratory. While a real laboratory design will likely include additional smaller rooms for mechanical equipment, control rooms, etc., these additional rooms need not be included in the design at this time.

Detector A: Detector A is a device of modest size (less than 1,000 kg of active material) that is sensitive to ionization and/or thermal excitation (phonons). A single laboratory might house several detectors of this type. Typical physics goals for Detector A might be a cold, dark matter search (successor to CDMS 2) or a bb decay experiment. Detector A may be operated at cryogenic or room temperatures but its sensitive material is solid and stable in the event of a loss of cooling or electrical power. Detector A requires the lowest possible radioactive and electromagnetic backgrounds. The total power requirement of Detector A is 100 kW and the laboratory should have sufficient power to operate three such detectors simultaneously.

Detector B: Detector B is most likely a solar neutrino experiment with 1 kiloton of liquid scintillator. Detector B requires a well-developed capability for the storage, installation and operation of a large inventory of volatile and flammable material. A particular goal of Detector B is the lowest possible trigger energy threshold, so Detector B is highly sensitive to radioactivity at energies <1 MeV. Although Detector B uses high-gain photodetectors, a design goal for Detector B is single photoelectron sensitivity. For that reason, Detector B also requires a high level of attention to electromagnetic interference from pumps and other motors and to ground loops. The finished size of Detector B, including its immediate ancillary equipment, is 60 m by 18 m by 18 m high. The electrical power requirements of Detector B are 500 kW.

Detector C: Detector C is a high-resolution tracking neutrino and proton decay detector containing 5 kilotons of liquid argon or xenon. The salient design feature of Detector C is risk management for a large inventory of a suffocating liquid cryogen in a confined underground location. Because of its tracking properties, Detector C is not particularly sensitive to low energy radioactivity, although a lower background trigger rate is always better than a higher one. The sensitive volume of Detector C is about 3,000 m^3. The electrical power requirements of Detector C are 500 kW.

Detector D: Detector D is a large water Cerenkov detector with a fiducial mass an order of magnitude larger than the Superkamiokande detector. Depending on its depth and the radioactivity of the surrounding rock, Detector D will likely require some outer volume of water as an active shield. For this evaluation, the active volume of Detector D will be 500,000 m^3 in the “rural mailbox” geometry. An additional area 50 m by 18 m by 18 m in height will be required for a purification systems and an instrumentation/physicist work area.

III. Standard Site

For the purposes of comparison, the Technical Subcommittee defines a standard site as having following properties:

(1) Free and clear volumes of the sizes specified with a wall surface appropriately stabilized to minimize wall movement, exfoliation, water leakage and dust.

(2) Two independent means of either horizontal or vertical access, designed to minimize access time and maximize access flexibility for personnel and instrumentation. The Sub-Committee sets as a goal the ability to deliver underground a standard international shipping container of cross-section 9 feet by 9 feet (with extra space for wheels), nominal length 20 feet and maximum total weight of 30 short tons, while keeping the container in a horizontal position. The Sub-Committee understands that some sites may not be able to meet all of these requirements without a level of expenditure that seems inappropriate. In such case, the proposers should indicate the current access restrictions and the cost and schedule to attain a reasonable level of improved access. The proposers should make clear the access restrictions that would remain with these improvements.

(3) A ventilation system capable of maintaining an ambient temperature of approximately 18° C with a relative humidity of less than 60 percent and sufficient fresh air flow to both (a) meet standards for personnel-occupied working spaces and (b) to limit radon concentrations to less than 10 percent excess

of the level measurable outside the laboratory site. The Sub-Committee is interested in strategies and costs for controlling dust and water in the various laboratory sites. The ability of a site to provide additional air to support the use of diesel equipment for excavations is of interest to the Sub-Committee, but is not required.

(4) Three-phase, 440 V electrical power at the specified level. Sites in which the electrical power is particularly "dirty" or interruptible need to include costs for power conditioning and back-up power supplies.

(5) A radiation background level equivalent to that achievable in salt at 5,000 mwe depth. Sites with uranium-thorium backgrounds and sites shallower than 5,000 mwe may also be acceptable, but the cost of shielding required to achieve these levels shall be included in the site cost.

(6) A fire suppression system capable of dealing with ordinary laboratory hazards. The additional cost of fire suppression systems required for flammable detectors and the cost of safety systems for detectors with large inventories of suffocating gases should be considered as a detector cost rather than a site cost.

(7) T1 or better Internet access and a multi-fiber optic cable connection to the outside for Internet, telephone, timing signals, etc.

(8) A cooling system capable of dissipating 1 MW if the rock ambient temperature is less than 20° C and 1 MW plus the rock heat load if the rock ambient temperature is more than 20° C.

IV. Evaluation Parameters

The technical evaluation will estimate the following parameters for each of the Detectors A, B and C for each of the proposed sites. The estimates for Detector D will be limited to feasibility and rough cost estimates as described earlier.

Cost and Time to Prepare Site: Beginning with the current condition of the site, what is the cost and time to prepare the site to meet the required specifications of each experiment. This cost and time does not include the actual building, installation and operation of the experiment, but it does include any require remediation of the site, including installation of a passive or active radiation or electromagnetic shield to reduce background radiation to the standard level.

Annual Operations Cost: This is the annual cost of operating the site itself, not including the cost of operating any specific experiments. These costs include rent or mortgage amortization, if any, personnel costs, maintenance costs, including allowance for depreciation and equipment replacement, electricity and other expendables.

Capital and operating cost estimates should follow the work breakdown structure described below.

Risk: A large number of risk factors are associated with the operation of an underground laboratory. The risks to be evaluated for each site include at least the following: (a) injury to personnel or damage to equipment by accident, fire, explosion, collapse or other hazard; (b) risk of delay and/or increased cost in development of the laboratory or the installation of the detectors due to ownership, interference of other activities, political, environmental or other factors; (c) risk of loss of use of the site; (d) risk of compromise to physics results; (e) risk of adverse liability judgments or workers compensation claims.

V. Work Breakdown Structure

Consultants for the Sub-Committee have prepared the following capital and operating work breakdown structures (WBS). The level of detail presented here is intended only as a guide to proposers. **The Sub-Committee does not expect to receive a cost for each site for each entry in the**

WBS. The Sub-Committee requests aggregate capital and operating cost estimates, along with itemized sub-costs that are roughly congruent to the Level 0 entries in the WBS. The lower levels of the WBS are an indication of which costs should be included in which Level 0 entries. If some Level 1 or lower entries have particularly large associated costs (>$5 million capital or $0.5 million operating), then these costs should be separately identified. Proposers should also indicate which costs will be funded in cash, in kind or with existing facilities by proposers or others outside of the NSF and DOE.

Underground Physics Facility Capital Work Breakdown Structure

1. Land Acquisition, Easements & Usage Fees
    - 1.1. 1.1. Surface Land Costs
    - 1.2. 1.2. Underground Rights Costs
    - 1.3. 1.3. Road Easements
    - 1.4. 1.4. Utility Easements
    - 1.5. 1.5. Public/Private Road Fees
2. 2. Surface
    - 2.1. 2.1. Access roads
    - 2.2. 2.2. Parking
    - 2.3. 2.3. Site Work
        - 2.3.1. 2.3.1. Clearing & Grubbing
        - 2.3.2. 2.3.2. Earthwork
        - 2.3.3. 2.3.3. Foundations
    - 2.4. 2.4. Surface Infrastructure
        - 2.4.1. 2.4.1. Electrical
        - 2.4.2. 2.4.2. Cooling
        - 2.4.3. 2.4.3. Water
        - 2.4.4. 2.4.4. Sewer
        - 2.4.5. 2.4.5. Communications
        - 2.4.6. 2.4.6. Compressed Gases
    - 2.5. 2.5. Buildings
        - 2.5.1. 2.5.1. Building 1-Visitor's Center & Administration
            - 2.5.1.1. 2.5.1.1. Meeting Rooms
            - 2.5.1.2. 2.5.1.2. Computer Support (including LAN and external connections)
            - 2.5.1.3. 2.5.1.3. Canteen
            - 2.5.1.4. 2.5.1.4. Operations staff area
            - 2.5.1.5. 2.5.1.5. Intellectual Programs
            - 2.5.1.6. 2.5.1.6. Visitor Work Area
        - 2.5.2. 2.5.2. Building 2-Housing
            - 2.5.2.1. 2.5.2.1. Sleeping rooms
            - 2.5.2.2. 2.5.2.2. Common rooms
            - 2.5.2.3. 2.5.2.3. Recreation facilities
        - 2.5.3. 2.5.3. Building 3-Warehouse & Assembly
            - 2.5.3.1. 2.5.3.1. Loading & unloading facilities
            - 2.5.3.2. 2.5.3.2. Storage
            - 2.5.3.3. 2.5.3.3. Clean room(s)
            - 2.5.3.4. 2.5.3.4. Crane areas
            - 2.5.3.5. 2.5.3.5. Machine shop
            - 2.5.3.6. 2.5.3.6. Shuttle Garage
        - 2.5.4. 2.5.4. Building 4-Laboratories
            - 2.5.4.1. 2.5.4.1. Chemistry
            - 2.5.4.2. 2.5.4.2. Physics & electronics
            - 2.5.4.3. 2.5.4.3. Clean room(s)
    - 2.6. 2.6. Surface Physics
        - 2.6.1. 2.6.1. Access
        - 2.6.2. 2.6.2. Site Preparation
        - 2.6.3. 2.6.3. Infrastructure
        - 2.6.4. 2.6.4. Communications
    - 2.7. 2.7. Rock Disposal Areas
        - 2.7.1. 2.7.1. Haulage Roads
        - 2.7.2. 2.7.2. Disposal Site Preparation
        - 2.7.3. 2.7.3. Environmental Requirements
        - 2.7.4. 2.7.4. Disposal Site Reclamation
3. 3. Underground Access
    - 3.1. 3.1. Shaft(s), Hoist(s) & Headframe(s)
        - 3.1.1. 3.1.1. Access Shaft
            - 3.1.1.1. 3.1.1.1. Hoist & headframe

- 3.1.1.2. 3.1.1.2. Primary support & lining
- 3.1.1.3. 3.1.1.3. Waterproofing & drainage
- 3.1.1.4. 3.1.1.4. Steel & concrete structures
- 3.1.1.5. 3.1.1.5. Electrical service
- 3.1.1.6. 3.1.1.6. HVAC
- 3.1.1.7. 3.1.1.7. Communications
- 3.1.2. 3.1.2. Secondary Shaft
  - 3.1.2.1. 3.1.2.1. Hoist & headframe
  - 3.1.2.2. 3.1.2.2. Primary support & lining
  - 3.1.2.3. 3.1.2.3. Waterproofing & drainage
  - 3.1.2.4. 3.1.2.4. Steel & concrete structures
  - 3.1.2.5. 3.1.2.5. Electrical service
  - 3.1.2.6. 3.1.2.6. HVAC
  - 3.1.2.7. 3.1.2.7. Communications
- 3.2. 3.2. Portal(s)
  - 3.2.1. 3.2.1. Access tunnel portal
    - 3.2.1.1. 3.2.1.1. Earthwork
    - 3.2.1.2. 3.2.1.2. Soil & rock retainage
    - 3.2.1.3. 3.2.1.3. Portal structure
    - 3.2.1.4. 3.2.1.4. Waterproofing & drainage
    - 3.2.1.5. 3.2.1.5. Access control
  - 3.2.2. 3.2.2. Egress tunnel portal
    - 3.2.2.1. 3.2.2.1. Earthwork
    - 3.2.2.2. 3.2.2.2. Soil & rock retainage
    - 3.2.2.3. 3.2.2.3. Portal structure
    - 3.2.2.4. 3.2.2.4. Waterproofing & drainage
    - 3.2.2.5. 3.2.2.5. Access control
- 3.3. 3.3. Tunnel(s)
  - 3.3.1. 3.3.1. Access Tunnel
    - 3.3.1.1. 3.3.1.1. Primary support & lining
    - 3.3.1.2. 3.3.1.2. Waterproofing, drainage & humidity control
    - 3.3.1.3. 3.3.1.3. Surface finishes
    - 3.3.1.4. 3.3.1.4. Floor slabs
    - 3.3.1.5. 3.3.1.5. Steel & concrete structures
    - 3.3.1.6. 3.3.1.6. Electrical service & alarms
    - 3.3.1.7. 3.3.1.7. Lighting
    - 3.3.1.8. 3.3.1.8. HVAC & fume control
    - 3.3.1.9. 3.3.1.9. Fire protection
    - 3.3.1.10. 3.3.1.10. Communications
  - 3.3.2. 3.3.2. Egress Tunnel
    - 3.3.2.1. 3.3.2.1. Primary support & lining
    - 3.3.2.2. 3.3.2.2. Waterproofing, drainage & humidity control
    - 3.3.2.3. 3.3.2.3. Surface finishes
    - 3.3.2.4. 3.3.2.4. Floor slabs
    - 3.3.2.5. 3.3.2.5. Steel & concrete structures
    - 3.3.2.6. 3.3.2.6. Electrical service & alarms
    - 3.3.2.7. 3.3.2.7. Lighting
    - 3.3.2.8. 3.3.2.8. HVAC & fume control
    - 3.3.2.9. 3.3.2.9. Fire protection
    - 3.3.2.10. 3.3.2.10. Communications

4. 4. Underground Facilities
   - 4.1. 4.1. Caverns
     - 4.1.1. 4.1.1. Common Area Cavern
       - 4.1.1.1. 4.1.1.1. Primary support & lining
       - 4.1.1.2. 4.1.1.2. Waterproofing, drainage & humidity control
       - 4.1.1.3. 4.1.1.3. Surface finishes
       - 4.1.1.4. 4.1.1.4. Floor slabs
       - 4.1.1.5. 4.1.1.5. Steel & concrete structures
       - 4.1.1.6. 4.1.1.6. Electrical service & alarms
       - 4.1.1.7. 4.1.1.7. Lighting

- 4.1.1.8. 4.1.1.8. HVAC & fume control
- 4.1.1.9. 4.1.1.9. Fire protection
- 4.1.1.10. 4.1.1.10. Communications

4.1.2. 4.1.2. Utility Cavern
- 4.1.2.1. 4.1.2.1. Primary support & lining
- 4.1.2.2. 4.1.2.2. Waterproofing, drainage & humidity control
- 4.1.2.3. 4.1.2.3. Surface finishes
- 4.1.2.4. 4.1.2.4. Floor slabs
- 4.1.2.5. 4.1.2.5. Steel & concrete structures
- 4.1.2.6. 4.1.2.6. Electrical service & alarms
- 4.1.2.7. 4.1.2.7. Lighting
- 4.1.2.8. 4.1.2.8. HVAC & fume control
- 4.1.2.9. 4.1.2.9. Fire protection
- 4.1.2.10. 4.1.2.10. Communications

4.1.3. 4.1.3. Experimental Cavern A
- 4.1.3.1. 4.1.3.1. Primary support & lining
- 4.1.3.2. 4.1.3.2. Waterproofing, drainage & humidity control
- 4.1.3.3. 4.1.3.3. Surface finishes
- 4.1.3.4. 4.1.3.4. Floor slabs
- 4.1.3.5. 4.1.3.5. Steel & concrete structures
- 4.1.3.6. 4.1.3.6. Electrical service & alarms
- 4.1.3.7. 4.1.3.7. Lighting
- 4.1.3.8. 4.1.3.8. HVAC & fume control
- 4.1.3.9. 4.1.3.9. Fire protection
- 4.1.3.10. 4.1.3.10. Communications

4.1.4. 4.1.4. Experimental Cavern B
- 4.1.4.1. 4.1.4.1. Primary support & lining
- 4.1.4.2. 4.1.4.2. Waterproofing, drainage & humidity control
- 4.1.4.3. 4.1.4.3. Surface finishes
- 4.1.4.4. 4.1.4.4. Floor slabs
- 4.1.4.5. 4.1.4.5. Steel & concrete structures
- 4.1.4.6. 4.1.4.6. Electrical service & alarms
- 4.1.4.7. 4.1.4.7. Lighting
- 4.1.4.8. 4.1.4.8. HVAC & fume control
- 4.1.4.9. 4.1.4.9. Fire protection
- 4.1.4.10. 4.1.4.10. Communications

4.1.5. 4.1.5. Experimental Cavern C
- 4.1.5.1. 4.1.5.1. Primary support & lining
- 4.1.5.2. 4.1.5.2. Waterproofing, drainage & humidity control
- 4.1.5.3. 4.1.5.3. Surface finishes
- 4.1.5.4. 4.1.5.4. Floor slabs
- 4.1.5.5. 4.1.5.5. Steel & concrete structures
- 4.1.5.6. 4.1.5.6. Electrical service & alarms
- 4.1.5.7. 4.1.5.7. Lighting
- 4.1.5.8. 4.1.5.8. HVAC & fume control
- 4.1.5.9. 4.1.5.9. Fire protection
- 4.1.5.10. 4.1.5.10. Communications

4.1.6. 4.1.6. Experimental Cavern D (only aggregates estimates are desired)
- 4.1.6.1. 4.1.6.1. Primary support & lining
- 4.1.6.2. 4.1.6.2. Waterproofing, drainage & humidity control
- 4.1.6.3. 4.1.6.3. Surface finishes
- 4.1.6.4. 4.1.6.4. Floor slabs
- 4.1.6.5. 4.1.6.5. Steel & concrete structures
- 4.1.6.6. 4.1.6.6. Electrical service & alarms
- 4.1.6.7. 4.1.6.7. Lighting
- 4.1.6.8. 4.1.6.8. HVAC & fume control
- 4.1.6.9. 4.1.6.9. Fire protection
- 4.1.6.10. 4.1.6.10. Communications

4.1.7. 4.1.7. Refuge Cavern
- 4.1.7.1. 4.1.7.1. Primary support & lining

4.1.7.2. 4.1.7.2. Waterproofing, drainage & humidity control
4.1.7.3. 4.1.7.3. Surface finishes
4.1.7.4. 4.1.7.4. Floor slabs
4.1.7.5. 4.1.7.5. Steel & concrete structures
4.1.7.6. 4.1.7.6. Electrical service & alarms
4.1.7.7. 4.1.7.7. Lighting
4.1.7.8. 4.1.7.8. HVAC & fume control
4.1.7.9. 4.1.7.9. Fire protection
4.1.7.10. 4.1.7.10. Communications
4.2. 4.2. Tunnels
4.2.1. 4.2.1. "Main Street" Tunnel
4.2.1.1. 4.2.1.1. Primary support & lining
4.2.1.2. 4.2.1.2. Waterproofing, drainage & humidity control
4.2.1.3. 4.2.1.3. Surface finishes
4.2.1.4. 4.2.1.4. Floor slabs
4.2.1.5. 4.2.1.5. Steel & concrete structures
4.2.1.6. 4.2.1.6. Electrical service & alarms
4.2.1.7. 4.2.1.7. Lighting
4.2.1.8. 4.2.1.8. HVAC & fume control
4.2.1.9. 4.2.1.9. Fire protection
4.2.1.10. 4.2.1.10. Communications
4.2.2. 4.2.2. Connecting Tunnels
4.2.2.1. 4.2.2.1. Primary support & lining
4.2.2.2. 4.2.2.2. Waterproofing, drainage & humidity control
4.2.2.3. 4.2.2.3. Surface finishes
4.2.2.4. 4.2.2.4. Floor slabs
4.2.2.5. 4.2.2.5. Steel & concrete structures
4.2.2.6. 4.2.2.6. Electrical service & alarms
4.2.2.7. 4.2.2.7. Lighting
4.2.2.8. 4.2.2.8. HVAC & fume control
4.2.2.9. 4.2.2.9. Fire protection
4.2.2.10. 4.2.2.10. Communications
4.3. 4.3. Underground Infrastructure
4.3.1. 4.3.1. Electrical
4.3.2. 4.3.2. Cooling
4.3.3. 4.3.3. Water
4.3.4. 4.3.4. Sewer
4.3.5. 4.3.5. Communications
4.3.6. 4.3.6. Compressed Gases
5. 5. Permits, Fees and Professional Services
5.1. 5.1. Environmental Impact Studies
5.2. 5.2. Professional Services
5.2.1. 5.2.1. Conceptual Design
5.2.2. 5.2.2. Design Development
5.2.3. 5.2.3. Construction Documents
5.2.4. 5.2.4. Construction Services
5.3. 5.3. Building & Occupancy Permits
6. 6. Cost of Money
6.1. 6.1. Short-term Loans
7. "Quality of Life" Issues
7.1 Living Essentials
7.1.1 Housing
0.1.1.1 Apartment
0.1.1.2 Hotels/Motels
7.1.2 Transportation
7.1.2.1 Air Connections
7.1.2.2 Rail Connections
7.1.2.3 Highway Connections
7.1.2.4 Motorpool or Vehicle Rental
7.1.3 Food & Shopping

7.1.3.1 Restaurants
7.1.3.2 Stores
7.1.4 Entertainment
7.1.4.1 Nearest Town
7.1.4.2 Theater/life
7.2.5 Transportation from Housing to Site

7.2.6 Intellectual Environment
7.2.6.1 Visitor's Program
7.2.6.2 Theory program
7.2.6.3 Seminar Program
7.2.6.4 University Host Functions
7.2.6.5 Library

Underground Physics Facility Operating Work Breakdown Structure

1. Fees
    - 1.1 Rental Fees
        - 1.1.1 Surface Land Costs
        - 1.1.2 Underground Rights Costs
        - 1.1.3 Buildings
    - 1.2 Easements
    - 1.3 Usage Fees
        - 1.3.1 Roads

2. Utility Costs
    - 2.1 Electrical
        - 2.1.1 Lighting
        - 2.1.2 Ventilation
        - 2.1.3 Hoisting
        - 2.1.4 Pumping
        - 2.1.5 Experiments
    - 2.2 Water
    - 2.3 Sewer
    - 2.4 Communications
    - 2.5 Waste Services

3. Maintenance
    - 3.1 Access roads
    - 3.2 Surface Buildings
    - 3.3 Portal
    - 3.4 Shafts, Hoists, Cages
    - 3.5 Access Tunnels
    - 3.6 Common Areas
    - 3.7 Connecting Tunnels
    - 3.8 Caverns
    - 3.9 Systems
        - 3.9.1 Electrical
        - 3.9.2 Mechanical
        - 3.9.3 Water
        - 3.9.4 Sewer
        - 3.9.5 Communications

4. Equipment & Transportation
    - 4.1 Shuttles
    - 4.2 Surface Equipment
    - 4.3 Underground Equipment
    - 4.4 Supply Shops
    - 4.5 Common Laboratories

5. Staff
    - 5.1 Administration
    - 5.2 Operations
    - 5.3 Maintenance

- 5.4 Technical Staff
- 5.5 Food Service
- 5.6 Public Relations

6. Outside Costs & Subcontracts
    - 6.1 Transportation
    - 6.2 Food Service
    - 6.3 Fire
    - 6.4 Maintenance
    - 6.5 Insurance
        - 6.5.1 Liability
        - 6.5.2 Environmental
        - 6.5.3 Closure Bond

Appendix C: Comparison of Select Characteristics and Costs of Four Principal Candidate Sites

	CUNL	Homestake	San Jacinto	Soudan
mwe[a]	1600[h] 1840[i] 3172[j] (3524)[k]	6156[j] (6700)[k] 6656[j] (7100)[k]	A: 5000[l] B: 6000[l] C: 6510[l] D: 7000[l]	2200[m]
Depth (m)	655 1300	2255 2438	See note u	710
Depth (ft)	2150 4265	7400 8000	See note u	2300
Density Figure of Merit[b]	2.44 [n]$11/ton [o]$23/m^3 [p]$25/m^2	2.73 $140/m^3 [q]$50/ton	2.73 [r]$73/m^3	3.1
LII Factor[c]	1.1	1.05-1.1	1	1.2
Halls	$5.9M[o] 3 halls of 15m x 10m x 100m	$40M[s] for 3 halls of 18m x 18m x 100m	$33M[t] 3 halls of 20m x 20m x 100m	
Cavern D[d]	See note u	See note u	$81.8M[v]	$70M[w]
Cost of Operations Cost of Access[e]	($0M) $2-10M/year[x] ($0M) $40M-$200M over 20 year lifetime [z]$43.6M +($14.2)	$3.8M/year[y] $76M over 20 year lifetime $43M[aa]	$2.3M/year[y] $46M over 20 year lifetime $51M[bb] $65M[bb] $82M[bb]	$1M/year[w] $20M over 20year lifetime $21M[w]
Declared Contingency	25%		25%	
Surface Building Costs[f] Total[g]	25kft^2 = $6M +$10M $63.7M ($104M)	3 bldg = $53M 32kft^2; 175kft^2; 41kft^2 $83M ($159M)	$18kft^2 warehouse + 12k ft^2 lab + $30kft^2 Admin = $6.6M $115M ($161M)[cc]	

Appendix C (continued)

Notes:

a) Meter water equivalent.
b) The figure of merit is the nominal cost per unit of excavated material.
c) Labor Installation Inefficiency Factor: An estimated multiplier on installation labor hours as a result of accessibility. The total labor costs are nominally <40% of the total cost of a detector.
d) Cavern of size required for "ultra-K" type detector (see Appendix B).
e) Cost of providing access, tunnel excavation, etc. to experimental chamber area.
f) From material presented by site advocates.
g) Total is Access + Chambers. Numbers in parenthesis represent costs including operations (surface buildings excluded).
h) Hime, et al.
i) Derived by nominal density with 1000 ft depth of rock, 1150 ft depth of salt, and muon angular distribution.
j) Derived by nominal density and depth.
k) Takes into account flat surface and muon angular distribution.
l) Minimum shield hemisphere radius intersecting mountain surface.
m) Experimentally measured.
n) Provided by WIPP engineer.
o) Taken directly from WIPP presentation materials.
p) Additional cost per square area of support (rock bolts, mesh, etc.) that must be provided on back or cavern.
q) Supplied by Homestake Mining Co. engineer.
r) Derived weighted average from numbers provided by San Jacinto advocates with $98/m^3 for top heading excavation and $65/m^3 with 0.25(top heading) + 0.75(bench).
s) Phase I from Homestake white paper. The cost for the miners necessary for the construction of detector chambers at the 7400ft level.
t) Presented to Technical Subcommittee by San Jacinto advocates.
u) Information not provided by site advocates.
v) Engineering estimate from CNA Engineers for dry, stable cavern with floor slab.
w) From Soudan representative: new shaft to 710m at $30k/m.
x) From CUNL presentation materials. Site advocates indicated that bare bones operating level would be zero, while the $2M - $10M/year is derived from a level of support staff for a scientific laboratory.
y) Stated by site advocates 3 March 2001 at Underground Committee Meeting.
z) From CUNL presentation materials. Costs shown are new shaft and miscellaneous access equipment in parenthesis.
aa) Phase II of Homestake development: Yates shaft extension and hoist upgrades.
bb) Tunneling costs presented by site advocates.
cc) Only option C with 6510 mwe shown.

Appendix D: Preliminary Evaluation of Additional Green Field Sites in Nevada and California

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Additional green field sites (i.e. undeveloped sites without extensive existing tunnels and deep mines) in Nevada and California are evaluated with attributes articulated by the Technical Sub-Committee of the National Underground Laboratory Committee. The sites include 1) Charleston Peak between Las Vegas and Pahrump in Nevada, 2) Telescope Peak between Panamint Valley and Death Valley, California, 3) Mount Tom and Mount Morgan west of Bishop, California and 4) Boundary Peak of the White Mountains on the Nevada state line. This evaluation is a supplement to site development plans for the Homestake Gold mine, South Dakota and Soudan Iron Mine, Minnesota, both with vertical access; Carlsbad Waste Isolation Pilot Plant, New Mexico, with new shafts to greater depths; and Mt. San Jacinto, California, with new nearly horizontal tunneling.

A large number of potential sites for a national underground science laboratory exist in the California-Nevada region. The sites presented here were chosen to probe a range of options for a deep underground laboratory. This preliminary evaluation is premature to represent the sites for final proposals or in site selection. Naturally, these sites many not share some of the attributes of the San Jacinto site near Palm Springs, California – three of them are in more remote locations, for example. For the purpose of reexamining the options within the California-Nevada region we have attempted to locate sites that:

• Present the opportunity for partnering with local and state governmental agencies in the construction of a mutually beneficial tunnel. This option follows the Gran Sasso model (the National Underground Laboratory of Italy) of sharing a highway tunnel with a scientific laboratory. To this end the **Charleston Peak** location was investigated.

• Present very deep options, in excess of 3,000m (9,843 ft) of overburden (elevation difference between peak and portal of a horizontal tunnel). **Telescope Peak** near Death Valley represents this option for extreme depth using horizontal access.

• Present the opportunity for assuming ownership of patented and unpatented claims and the use of existing mining and other permits for the expansion of an existing mining claim into a national underground laboratory. The soon-to-close **Pine Creek Mine**, while bordered by national forest land and wilderness regions in the California Sierras, presents a potential deep site with several of the permitting issues facing other proposed sites either already solved or only requiring modification of existing permits and not requiring entirely new permits.

• Present an approximate analog to the Mt. San Jacinto proposal, but in a state in which the mining industry represents a larger share of the economy. The **Boundary Peak** site provides similar overburden opportunities, similar geological features, and comparable tunneling lengths, however located in Nevada.

The following table summarizes the four sites evaluated in this report. It is stressed that a preliminary investigation of these sites is presented here, with as much information and supporting documentation as we could obtain within limited resources and time constraint.

Additional Potential Sites for Locating a National Underground Science Laboratory

Peak, Underground Lab Location		

Nearly Horizontal Tunnel Portal *Inclined Tunnel Portal*	Depth (m)	Elevation (m)	Tunnel Length (km)	Upward Grade	Orientation (deg. angle)
	Las Vegas, Nevada				
Charleston Peak	**1828**	**3633**			
Peak Spring Canyon, Pahrump		1707	9.7	1%	38
Kyle Canyon, Highway 137		*2073*	*8.5*	*3%*	*-6*
Charleston Peak	**2406**	**3633**			
Manse, Pahrump		1036	19.0	1%	26
Kyle Canyon, Highway 137		*2073*	*8.5*	*10%*	*-6*
	Death Valley, California				
Telescope Peak	**2923**	**3367**			
Panamint Flat Dry Lake		323	12.1	1%	24
Hanaupah Canyon, South Fork		*1219*	*6.0*	*13%*	*15*
	Pine Creek Valley, California				
Mount Tom	**2454**	**4161**			
Inyo National Forest, South of Royana		1646	6.1	1%	-137
Pine Creek Mill		*2469*	*4.9*	*16%*	*149*
Mount Morgan	**2521**	**4190**			
Inyo National Forest, Ranger Station		1573	9.7	1%	-155
Pine Creek Mill		*2469*	*5.6*	*14%*	*-63*
	Boundary Peak, Nevada				
Boundary Peak	**1815**	**4005**			
Von Schmidt Line		2134	5.7	1%	-45
Morris Creek		*2170*	*5.2*	*0%*	*138*

Site Attribute and Evaluation Approach

Depth (overburden thickness) of the proposed laboratory is the most important attribute of a site to be considered for the next generation of neutrino, nuclear science, and high energy physics experiments in the National Underground Science Laboratory. In addition to depth (required to shield cosmic rays), the sites need to be investigated for access mode (horizontal tunnel, inclined ramp, or vertical shaft), extent of new tunneling/excavation, radiation background (from radiochemcial elements in the formation), construction feasibility and stability of large caverns, drainage, ventilation, seismic hazards, and other technical and operational considerations. The proximity to population centers and academic institutions, with the associated impact on science education for the next generation of students, is also a factor in evaluating the sites. This evaluation focuses on depths of underground chambers and lengths of access tunnels.

In this study, we choose 1,800 m (5,906 ft) as the minimum depth, measured from the peak to the test level accessible by a nearly horizontal (with 1% grade) tunnel. If a second tunnel is required, we can either excavate two parallel tunnels or excavate another shorter tunnel, using an inclined ramp. With monotonic decline from the underground laboratory to one portal, natural drainage can be maintained and the underground experiment chambers can be operated without costly pumping requirements. The portals at different elevations and different temperatures can also promote natural ventilation and reduce operational costs of forced ventilation. Because most mountain ranges are located in national forests, in wilderness areas, or in state or national park lands, the impact of a national underground facility was intentionally minimized and no shaft as an escape route through hoist and lift is considered. All portal sites evaluated here can be reached by four-wheel drive vehicles from routes identified on topographic maps by the National Forest Service and the United States Geological Service.

Charleston Peak, Las Vegas

The eastern foothill of the Charleston Peak (elevation 3,633 m or 11,918 ft) in the Spring Mountains can be reached by Highway 137, 40 km (24 miles) from the outskirts of Las Vegas. Las Vegas is the fastest growing metropolitan area of the United States, with a population of ~1.4 million. The city of Pahrump is on the other side of Charleston Peak. Clark County (where Charleston Peak and Las Vegas are located) and the neighboring Nye County (where Pahrump and the Nevada Test Site are located) have extensive tunneling resources, expertise, and experienced work force for construction projects.

A nearly horizontal tunnel can start from the Peak Spring Canyon east of Pahrump, reach a cover of 1,828 m (6,000 ft) in 9.7 km (6.1 miles), and exit to connect to Highway 137 in 8.5 km (5.2 miles). Both portals are in the Humboldt-Toiyabe National Forests, and the peak is below the wilderness area. Additional overburden can be obtained at this location by shifting the portal down slope. It is possible to add approximately 600 m (1,969 ft) of cover if we double the tunnel length and move the starting portal ~10 km (6 miles) closer to Pahrump (on Bureau of Land Management land).

Charleston Peak in the Spring Mountains has regional inactive faults separating limestone blocks from other hard rocks. The presence of faults requires careful site characterization and mining operation to anticipate rock failure in crossing the faults. The seismic hazard is relatively low at this site in comparison with other green field sites. The new tunnel can be constructed as part of an extension of Highway 137 to connect Las Vegas with Pahrump. This concept of associating test site with highway is similar to the case at Gran Sasso, Italy where three large halls were constructed for physics experiments. The underground lab is easily accessible through the highway tunnel.

Telescope Peak, Death Valley

Telescope Peak (elevation 3,367 m or 11,048 ft) can provide the rock cover of 2,923 m (9,591 ft) through 12.1 km (7.5 miles) horizontal access from the Panamint Valley. The portal is located at the northern end of Panamint Flat Dry Lake (elevation of 323 m or 1,060 ft). Ballarat (a gold mining ghost town) is 16 km (10 miles) south of the potential portal site. This portal is in private land outside the Bureau of Land Management Wilderness area. The peak is below the Death Valley National Monument land.

The second portal can be a steep inclined ramp, with exit 6 km (3.7 miles) east at the South Fork of Hanaupah Canyon. With the steep slope, water will not drain into the Death Valley National Monument, with the lowest point in the United States, 71 m (282 ft) below sea level. If the water quality is good, the drainage may be portable for Panamint Valley with resort and other business interests. The closest (~97 km or 60 miles) airport to Panamint Valley is in Inyokern with services to Los Angeles. The airport is near the China Lake Naval Air Weapons Station and the town of Ridgecrest.

Mount Tom and Mount Morgan, Pine Creek Valley

Mount Tom (elevation 4,161 m or 13,652 ft) and Mount Morgan (elevation 4,190 m or 13,748 ft) are in the high Sierras west of Bishop, California. Both peaks can be accessed with nearly horizontal tunneling to achieve over 2,438 m (8,000 ft) of rock cover. Mount Tom can be accessed 6.1 km (3.8 miles) from a location in the Inyo National Forest. Mount Morgan is higher in elevation and requires longer tunneling (9.7 km or 6 miles) from a National Forest Ranger Station at the foothill of Wheeler Ridge. Pine Creek Valley is bounded on the north by Mount Morgan and Wheeler Ridge, and on the south by Mount Tom. Both mountains are composed primarily of granitic and metamorphic rocks.

Pine Creek Mine within Pine Creek Valley is referred to as the "Mine in the Sky", since it uses horizontal accesses to reach tungsten ores above the tunnels. The Easy Go tunnel at an elevation of 2469 m (8,100 ft) is 3.2 km (2 miles) long, heading north toward the ore bodies between Mount Morgan (granitic) and Wheeler Ridge (metamorphic). The shorter Brownstone tunnel (with length of 0.8 km or 2,500 ft) is oriented to the south. The first parts of these Pine Creek Mine tunnels, located at the Pine Creek Mill site, are potential portal locations for inclined escape tunnels. Part of the existing tunnels may be used for escape tunnels. If the ramps from Pine Creek Mill are too steep, we may use other locations along the valley at lower elevations (and closer to the peak of Mount Tom) on national forest lands as exit points (for examples, the tailing ponds and the Scheelite site with gravel pits).

Observations from two existing tunnels from the Pine Creek Mill reveal many interesting features. The tunnels are wet at different locations, including the terminal end of the Easy Go tunnel, with ~1,219 m (4,000 ft) of overburden. The grade of ~0.5% is sufficient to drain large amount of seepage (millions of gallons per day, highest during spring runoffs along Morgan Creek). A long-standing arrangement to receive the ground water outflow exists with the local water control board. We observed that long sections of tunnel (hundreds of meters in length) do not require any rock or ground support, whatsoever. Natural ventilation is sufficient to maintain good air quality. Wide rooms (~25 m or 80 ft span), constructed decades ago, remain stable in stopes between the granite and marble structures. Radon gas control was needed during mining operations.

The mine has not been active for over ten years, with a diesel locomotive and the track still operational as of February 2001. The Pine Creek Mine is privately owned and is undergoing transfer of ownership for apparent salvage operations. The owner of the Pine Creek Mine was very open to discussions for scientific uses of the mine infrastructure. New tunnels may be treated as extensions of historical tunneling operations. The Pine Creek Mine has had decadal interactions with National Forest Services, Inyo County, and California Water Control Board. All of this information and mining experience are valuable for future tunneling development at these and similar sites and for dealing with permitting-granting agencies within forest, wilderness and publicly owned land in the West.

Boundary Peak, Nevada

Boundary Peak, the highest point in Nevada (elevation 4,005 m or 13,140 ft), is located at the northern tip of the White Mountains, ~64 km (40 miles) north of Bishop along Highway 6. The peak is accessible from three sides to achieve a cover of ~1,800 m (6,000 ft). The nearly northwest to southeast oriented approaches, one along the von Schmidt line (the historic state line between Nevada and California) and the other from Morris Creek, are 5.7 km (3.5 miles) and 5.2 km (3.3 miles), respectively. Sections of the tunnels are below valleys of the same orientation. It is also possible to excavate below more smooth landform and have the tunnel oriented in the north to south orientation, staring from the Queen Canyon mining district (with five or more existing or historical mining operations) to reach the Boundary Peak. The rock in Boundary Peak and White Mountains is mainly sedimentary.

Boundary Peak in Nevada provides similar covers and comparable tunneling lengths as Mt. San Jacinto in California. Mt. San Jacinto provides covers of 1,786 – 2,325 m (5,859 – 7,628 ft) with 4.7 – 7.6 km (2.9 – 4.7 miles) of nearly horizontal tunnels. Both sites are accessed with tunnels below valley floors. For tunneling into high-relief cliff face with rugged landform, the excavation needs to be carefully planned with detailed geologic mapping, water flow and geo-chemical/isotopic analyses, and geo-technical evaluations before and during mining operations. Unexpected delays in encountering hidden faults need to be avoided in any tunneling projects.

Other Potential Sites

The Sierras have many majestic high peaks, including Mount Whitney, the highest point in the continental United States (elevation 4,418 m or 14,494 ft). Many peaks have high relief accessible from the valley floors to reach over 2,438 m (8,000 ft) rock covers. White Mountains can also provide over 2,438 m (8,000 ft) cover. The White Mountains Research Station of the University of California is located on the summit. The White Mountains, like Wheeler Ridge, has a relatively flat ridge over large areas. In Nevada, we also recognize that Mount Grant (west of an Army Depot in the town of Hawthorne), and Wheeler Peak (east of Ely in the Great Basin National Park) are potential sites with positive attributes.

Summary

High-relief mountains are abundant in Nevada and California. An underground laboratory located at Charleston Peak near Las Vegas and at Boundary Peak on the Nevada-California state line could provide over 1,800 m (5,906 ft) of rock cover above test chambers. An additional cover on the order of 610 m (2,000 ft) could be added to Charleston Peak site if the portal is moved closer to Pahrump along a potential extension of Highway 137. Mount Tom and Mount Morgan could provide over 2,438 m (8,000 ft) of cover if the access tunnels were driven from flat land outside the Pine Creek Valley, with Pine Creek Mine tunnels as potential portals/extensions for escape tunnels. Mount Tom and Boundary Peak provide similar overburdens with comparable tunnel lengths as the Mt. San Jacinto site. Telescope Peak at Death Valley provides the greatest cover of 2,923 m (9,591 ft), among the sites evaluated. Systematic analyses of geologic, geotechnical, geohydrological and geochemical characteristics are needed to assess the technical, social-economical, and outreach-educational attributes in site selection for the next generation of science experiments.

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[1] Professor Calaprice is a participant in the Borexino Collaboration in the National Laboratory of Gran Sasso and has 10 years experience in underground science. Dr. Doe, Dr. Lesko and Professor Wilkerson are physicists, participating in the Sudbury Neutrino Observatory (SNO) Collaboration, working in the Creighton Mine in Sudbury, Canada. Professor Marshak, chair of the Technical Sub-Committee, is a participant in the Soudan 2 and MINOS Collaborations, working in the Soudan Mine in northeastern Minnesota. He was the founding director of that laboratory and has 21 years experience in underground science. Dr. Nelson and Dr. Petersen are professional engineers, specializing in underground civil construction projects for transportation, utilities, workspace, storage and other purposes. They have designed both the Soudan 2 and the MINOS halls at the Soudan Laboratory. Dr. Robinson is a physicist at the Lawrence Berkeley National Laboratory and has extensive experience in the planning and construction of large science projects. Dr. Wang is an experienced geophysicist at the Lawrence Berkeley National Laboratory.